FOREST MENSURATION FOR RANGERS

SARVESH KUMAR DUBEY

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for

RANGERS

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P R E F A C E   O F   A U T H O R

Object of Forest Management has been changed according to the present needs of the increasing populations and present set up of civilisation. The population at present is in need of not only the various forest produce like timber, firewood, charcoal, pulpwood and other industrial raw materials - but also for good ecological balance, environmental hygeine, recreation, wildlife, water shed management, protection of their fields and other property from devastating floods and erosion. The present day's people are interested in the indirect role of the forests also. Hence the demand of forest produce has to be met with from limited amount of natural forests and manmade forests. Commercial forestry with economy needs careful estimation and supply of forest produce. For such estimation and evaluation we require Forest mensuration.

For increase of production we are forming several corperations and new schemes under which economic and industrial plantations are being raised. But they have to be supplied on a sustained basis for the various developing industries. Hence, we are in need of the quantitative assessments, rate of growth, the Yield, etc. which can be achieved only through this subject. Hence Forest mensuration can be considered to be a very important subject, next to silviculture in forestry.

But for such important subject, there are very limited books published so far. No book covers the entire syllabus for the Rangers Course.

Hence I have tried to write this notes with the full encouragement and guidance of Shri M.L.Ramprakash, I.F.S., our Principal. All the important topics have been covered by me and I have tried to explain with lot of problems and about 170 illustrations. Important topics like espacement and number of plants, point sampling, measurement of height of leaning trees, etc. are not in Rangers syllabus. However these have been added in Appendices. I hope that this notes may be found useful not only for the Ranger trainees but also to the field forest officers during their practical application in the field.

I express my sincere thanks to Shri M.L.Ramprakash, I.F.S. who encouraged me, guided me and who went through most of the Chapters and gave me suggestions in writing this book.

My thanks is also due to Shri G.Balakrishnan, Sr. Stenographer of the Southern Forest Rangers College for having neatly typed this and Shri P.Raman, Artist of Forest Research Centre for having drawn all the sketches neatly.

Constructive suggestions are welcome for further improvement.

Coimbatore,
4th March, 1985.

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CHAPTER I

INTRODUCTION

1. Mensuration: Mensuration was an essential part of mathematics. This word is derived from the latin word mensura which means measure. Hence, it is concerned with the determination of lengths, areas and volumes. Forest mensuration is the mensuration as applied to the forests i.e., measurement of forests and forest products. In fact Forest Survey should strictly come within Forest mensuration. However, Forest Survey and Forest mensuration are taught as separate subjects in our colleges.

2. Forests: The word "Forest " is derived from the latin word "foris" which means out of doors. Forest means a large and uncultivated tract of land covered with trees and underwood as per Chamber's 20th century Dictionary. Forest is defined " as a plant community predominately of trees and other woody vegetation usually with a closed canopy" according to British Commonwealth Forest Terminology. Legally " forest includes any land declared as such from time to time by competent authority ". The Indian Forest Records define forest "as an area set aside for production of timber and other forest produce, or maintained under woody vegetation for certain indirect benefits it provides, e.g. climatic and protective".

3. Value of Forests: Forests are an essential part of the earth's geography. They are much valued for their aesthetic beauty and supply of various forest produce. We derive many goods through the woody products of trees i.e. timber and fuel and other parts of trees like leaves, fodder, bark, fruits, gum, etc. The services rendered by the forests are protection of soil from erosion, production of continuous flow of clean water, reduction of danger of floods, protection of crops and settlements from winds, excessive temperature, etc. You would study the value of forests in other subjects.

4. Measurement of Values: Indirect values cannot be measured. But direct values are amenable to measurement. Timber, fuel and other produce should be measured for the management of forests. Hence mensuration comes into picture.

5. Forestry: Forestry is defined as " an applied science dealing with the scientific management of forests including the theory and practice of their creation and conservation and utilisation of their resources. Hence, it is the management activity involving land, the plants and the animals growing in it.

6. 1. Place of Forest Mensuration in Forestry: Scientific forest management is sub-divided into 2 main branches as follows:

- Scientific Forest Management
  - Forest Bionomics
    - Silviculture (Theory & practice)
    - Forest Protection
  - Forest Economics
    - Forest Valuation & Finance
    - Forest Mensuration
    - Forest Utilisation

6.2 Forest Binomics deals with the study of living organisms in their reciprocal relationship to environment. This deals with establishment, development, care and reproduction of forest crops. But Forest economics considers forest as a productive asset whose value at a particular point of time and the increment over a period have to be assessed (Forest valuation) by taking measurements at suitable intervals (mensuration) and optimum mode of their utilisation decided upon (utilisation). There is intimate connection between the three subjects.

6.3 Forest valuation will explore the economic potentiality of the forest and prescribe measures to maximise returns on a sustained basis.

6.4 Forest mensuration sets out to assess the quantity of forest produce available at a particular point of time and growth rate over a period. Forest mensuration is not the end itself but a means to an end.

6.5 Felling, extraction, conversion, transport and marketing of the forest produce come in Forest utilisation. Hence neither forest valuation nor forest utilisation can go alone but requires Forest mensuration along with them.

7.1 Forest Mensuration

Definition: " Forest mensuration is that branch of forestry which deals with the determination of the dimensions (ex: diameter, height, etc.) form, volume, age and increment of single trees, stands or whole woods, either standing or after felling".

7.2 It includes measurement of felled and standing trees, sawn wood and round logs and various other products such as fuel, charcoal, pulpwood, fruits, etc. Hence forest mensuration is concerned with the linear, area, volume and weight measurements. Volume was essential all these days. But weight, referred to as biomass, is being increasingly used now in place of volume.

8.0 Objects of Forest mensuration:

The measurements taken under Forest mensuration serve the following objects.

8.1 Basis for management: The forests have to be managed properly so that it can meet the demand of timber and other forest produce in perpetuity. For this purpose, we require the quantity of timber and other forest produce available in the forests at a time, the age-war and size-war particulars of the trees along with the increment it is putting on every year or over a period of years. To get the above particulars, either the individual trees or sample plots will have to be measured so that data for the whole area can be deduced by the rule of proportions. Sometimes it may be necessary to measure the whole forests. To get the measurements we have developed methods of preparing forest inventories, using satellite imageries, aerial photographs, and various optical and electronic techniques so that forests can be harvested without depleting the capital.

8.2 Basis for Sale: Any forest manager will have to be the sellers of the forest products. Before selling anything, qualitative and quantitative assessments of the forest produce is essential. Trees may be sold as standing, or after felling or after

conversion or even after being subjected to manufacturing process. Depending upon the needs of the market, linear measurements or volume of logs or trees or sawn timber or stacked fuel or pulpwood, etc. are essential. In the olden days, forest produce was ample and demand was less. But now it is reverse. There is a big gap between the demand and availability. The prices of forest produce have increased. As auction is the main mode of sale in our departments, whenever the assessment of forest officers are less, the contractors are the actual benefit-makers. Before sale, we have to assess the quamtity and prepare the fair price statements. Sometimes sale will be in area basis as in the case of fuel or bamboo coupes. In all such cases, the valuation has to be based only on measurements for which forest mensuration is essential.

8.3 Measurement for Research:

Object of the management is to increase the production. This can be done only by adopting the best technique and giving suitable treatment to the forest area. This treatment will change depending upon the site conditions. Hence research is quite essential to do experiments to compare different treatments. This requires laying of sample plots and periodic measurements for which mensuration is a must.

8.4 Measurement for planning:

We are concerned about the future also. The population increases; civilisation increases; standard of living increases; Hence demand also increases. We have to plan to reduce the gap between demand and supply. Hence we have to accurately estimate the future yields. Forest mensuration gives the basic statistical data to plan for the future.

9.0 Scope of Forest Mensuration:

9.1 Forest mensuration has a very wide scope. It concerns not only with foresters, contractors, sawyers and transport labour but also the saw millers, wood-using public, etc. Whoever sells wood or purchases wood has to know about this. It helps in assessing the quantity of wood products and future yields of forest crops. It deals with felled trees as well as standing crops.

9.2 At present day's forest management, we have to do measurements for the purpose of Environmental Conservation, Ecological consideration, Soil and Water conservation, Wildlife management, Water shed management, Insect and Disease incidences, recreation, tourism and for such protective purposes also. We can tell that Forest mensuration is the foundation of measurement principles. Application of statistical theory and use of electronic computer for data processing have brought about many changes in forest measurement problems.

10.1 Accuracy in measurements:

Forest mensuration does not attempt in securing absolute mathematical accuracy. We do not want to assess the accurate measurement of timber for the purpose of sale as there will be lot of wastage of timber while conversion and use. Hence the Forest mensuration aims at reasonable accuracy i.e. maximum accuracy which is possible, profitable and practicable.

10.2 Reasons:

a) Characteristics of Trees: Trees are of different shapes i.e., short stems and big crowns; long stems and short crowns; sections of wood not always being circular; have different length and forms of trees; sections not following any definite geometrical form; degree of eccentricity varying from tree to tree; swelling near the base of the trees; fluiting, buttresses of trees; varying bark thickness. Hence no single formula can be used.

b) Varying methods and conditions of felling and conversion: The volume of timber in a tree depends upon the methods of felling and conversion and also local conditions. Careless felling and conversion leads to wastage of timber. In a hilly area rough squaring in the forests will be wasteful.

c) Instruments and conditions in which they are used:

What is the type of instrument used for measurement?

For example, Abney's level with its vernier gives only approximate angle. For the observer there should not be any obstruction: He should not have any shake while viewing the top of the tree. Linear measurement with a stretched tape will not be correct. Hence this will give only approximate height of trees. There will be natural obstructions in the forests to the measurer also. Further our presumption that the trees stand vertical and their sections are circular -- are all wrong as trees are seldom vertical and their sections are seldom circular.

d) Personal bias of the estimator: Prediction of volume of trees for future are done presuming that the trees will grow in similar conditions i.e. the conditions prevailing in the past will continue to be the same. Hence personal bios of the estimator influences the judgement and consequently the estimate of future yield.

e) Biological character of the forest: The growth of the forest is a function of several factors, acting simultaneously. These factors cannot be predicted with mathematical accuracy. Trees are all affected by climatic factor, soil factor, topographic factor and above all by the biotic factor. Hence growth rate of trees can be assessed only roughly.

f) Use: The accuracy depends upon the use to which the measurement is going to be put to. If the valuation has to be done for products like fuel, whose value is low, it will be a wastage to measure accurately the dimensions of all trees. An immature area does not require correct measurements as a mature timber forests. For research purposes, we need accurate measurements. If it is for sale, the degree of accuracy depends upon whether we are going to sell the standing growth or converted material. For converted material, accuracy should be more. A routine forest measurement need not be so accurate as in sample plots, which are used for statistical or research works.

g) Cost: When high accuracy is needed, it requires measurement of every tree. This consumes much time and requires high costs. Such accurate measurement of stands is not necessary as accuracy depends upon method of felling and conversion. The value of finished product is much less than the value of the trees. The

wastages in the intermediate operations cannot be assessed so easily. Any extra cost spent to get a high degree of accuracy than what is necessary is nothing but a waste. Hence it is not desirable to spend high cost on accuracy.

11.0 Units of measurement:

Systems of measurement: Following two systems of measurements have been commonly used.

a) British system of F.P.S. System.

b) French or Metric system or C.G.S. system (Centimetre gram second system)

British system was in vogue in Indian Forestry. But the metric system or C.G.S. system was introduced in October, 1962. It is now a legal necessity. Hence the old records of measurements are in British system. The records prepared after introduction of French system are in metric system. Hence we have to study both the systems as well as the conversions.

11.1 British system: Prior to 1-10-1958, this system was in vogue. Inches, feet, yards, chains, miles were the units of length. Square inches, square feet, square yards, acre and square miles were the units of area. Cubic inches and cubic feet, were the units of volume.

11.2 Metric system: But the position has changed with the passing of the standards weights and measures Act of 1956. The Act envisaged change-over from the British to metric measures over a period of 10 years from 1-10-1958.

Metric system is a system of weights and measures which was first adopted by France and is now almost universally adopted. As metre is the primary unit it is known as metric system. The three principal units in metric system are meter or metre, (unit of length) litre or liter (unit of capacity) and gram (unit of weight). Multiples of these units are obtained by prefixing the principal units, the Greek words dika or deca, (10 times), hecto (100 times) and kilo (1000 times), myria (10000 times) and mega (1,000,000 times). The sub-multiples or divisions are obtained by prefixing the Latin words deci (1/10 - one tenth), Centi (1/100 - one hundredth) and milli (1/1000 - one thousandth).

1 {metre / gram / litre} = 10 Deci {metres / grams / litres} = 100 Centi {metres / grams / litres}

= 1000 milli {metres / grams / litres}

1 kilo {metre / gram / litre} = 10 Hecto {metres / grams / litres} = 100 Deca {metres / grams / litres}

= 1000 {metres / grams / litres}

Metric numbers are written with decimal point (.) at the right of figures denoting the units. Thus, 18 metres 5 centi metres is written as 18.05 m. Similarly 56.746 is read as 56 metres, 746 millimetres.

11.3 Units of Length:

1) F.P.S. System

12 inches	1 foot
3 feet	1 yard
66 feet or 22 yards	1 chain = 100 links
10 chains or 220 yards	1 furlong
8 furlongs or 1760 yards	1 mile

2) C.G.S. System

10 millimetres (m.m.)	1 centimetre (cm)
10 centimetres (cm)	1 decimetre
10 decimetres	1 metre (m)
10 metres	1 decametre
10 decametres	1 hectometre
10 hectometres	1 kilometre
1852 metres	1 Nautical unit

In forestry, linear measurements are adopted in the following cases and the units in both systems are given below:

Particulars of linear measurement	In British system	In metric system
1. Height of a tree	To the nearest whole foot (Half or more of a foot to be treated as one)	In metres corresponding to the first place of decimal.
2. Length of sections of bole for stem analysis and sample plot works.	10 feet, the odd feet being included in the last section which does not exceed 15 feet.	3 metres, the last sections not exceeding 4-5 metres.
3. Diameter of trees or sections.	In inches to the nearest tenth of an inch.	In centimetres to the nearest 1/5th of a centimetre (i.e., to the nearest multiple of 2mm)
4. Girth	In inches to the nearest tenth of an inch.	In metres and to the nearest centimetre.
5. Height of the stump.	To the nearest inch	To the nearest centimetres.
6. Limit of standard stem timber.	Down to 8 inches diameter over bark.	Down to 20 centimetres diameters over bark.

Particulars of linear measurement	In British system	In metric system
7. Limits for standard small wood in bole and branches.	From under 8 inches diameter over bark to 2 inches diameter over bark.	From under 20 centimetres diametre over bark to 5 centimetres diameter over bark.
8. Height of seedlings	To the nearest inch	To the nearest centimetre.
	Other measurements	
a) Breast height for diameter measurement.	4.5 feet	1.37 metres
b) Diameter class interval	4 inches	10 c.m.
c) Area	In acres	In hectares
d) Top diameter	Average of 100 biggest diametres per acre	Average of 250 biggest diametres per hectare.
e) Bark thickness	Nearest 1/10 of an inch	Nearest m.m.
f) Number of annual rings	Per inch	Per 2 cms.
g) Basal area	Square feet	Square metre
h) Volume	Cubic feet	Cubic metres (with 2 or 3 decimal)

11.4 Units of Area:

a) British system:

144 sq. inches	=	1 square foot
9 square feet	=	1 square yard
484 square yards	=	1 square chain
10 square chains or 4840 sq. yards.	=	1 acre
640 acres	=	1 square mile

b) Metric system:

100 square millimetres	=	1 square centimetre
100 square centimetres	=	1 square decimetre
100 square decimetres	=	1 square metre
100 square metres	=	1 are or 1 square decametre
100 ares or sq.decametres	=	1 hectare
100 hectares	=	1 square kilometre

11.5 Units of Volume:

a) British system:

1728 cubic inches	=	1 cubic foot
27 cubic feet	=	1 cubic yard

b) Metric system:

1000 cubic millimetres	=	1 cubic centimetre
1000 cubic centimetres	=	1 cubic decimetre
1000 cubic decimetres	=	1 cubic metre

11.6 Units of weight:

a) British system:

10 ounces	=	1 pound
28 pounds	=	1 quarter
4 quarters	=	1 hundred weight
20 hundred weights	=	1 ton

b) Metric system:

10 grams	=	1 decagram
10 decagrams	=	1 hectogram
10 hectograms	=	1 kilogram
100 kilograms	=	1 quintal
1000 kgs. or 10 quintals	=	1 tonne

12.0 CONVERSION FACTORS:

Conversion factors of some commonly used units are given below:

FPS to CGS	CGS to FPS
1 inch = 25.4 mm	1 cm = 0.3937 inch
1 foot = 30.48 cm	1 metre= 1.09361 yards or 39.37 inches.
1 yard = 0.9144 m or 91.44 cm.	1 km = 0.62137 miles or 4.97 furlong or 3281 feet
1 furlong= 0.201 km or 201.168 m.	
1 mile = 1.609 km or 1609 m.	

Area

1 sq. inch = 6.4516 sq.cm.	1 sq. metre = 1.19599 sq. yards or 10.7639 sq.ft.
1 sq. ft. = 9.2903 sq. decimetres	
1 sq. yard = 0.83613 sq.m.	1 hectare = 2.47105 acres
1 acre = 0.40468 ha.	
1 sq. mile = 2.58999 sq.km.	1 sq.km. = 0.386101 sq. miles.
1 sq.ft. per acre = 0.230 sq.m/ha.	1 sq.m/ha.= 4.356 sq.ft./acre

FPS to CGS		CGS to FPS	
Volume			
1 cubic inch	= 16.3872 cu.m.	1 cubic cm	± 0.0610 cu. inch.
1 cft	= 0.0283 cu.m.	1 cubic metre	= 35.3147 cubic feet
1 cft/acre	= 0.070 cu.m./ha.	1 cu.m./ha.	= 14.291 cft/acre.
Weight			
1 pound	= 0.4535924 kg.	1 kilogram	= 2.20462 pounds
1 ton	= 1.01605 metric tonnes	1 metric tonne	= 0.98420 ton.

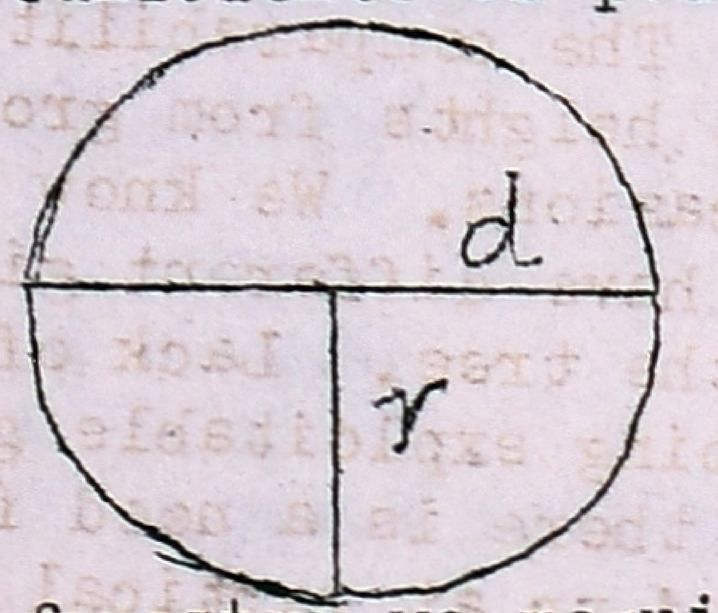
CHAPTER II

MEASUREMENTS OF DIAMETERS AND GIRTHS

1.1 Linear measurement: This is the fundamental measurement for any mensurational work. This can be obtained directly by any length measuring instrument such as wooden or plastic scale or a measuring tape. It can also be obtained indirectly by the use of principles of Geometry or Trigonometry. The circumference of curved figures may be measured by running the tape or running a cord round it and measuring it by a wooden scale or plastic scale. It can also be obtained by the formula, if diameter or radius is known.

Circumference or perimeter of a circle: $2\pi r$ or πd

where π = 3.141526
d = diameter
r = radius



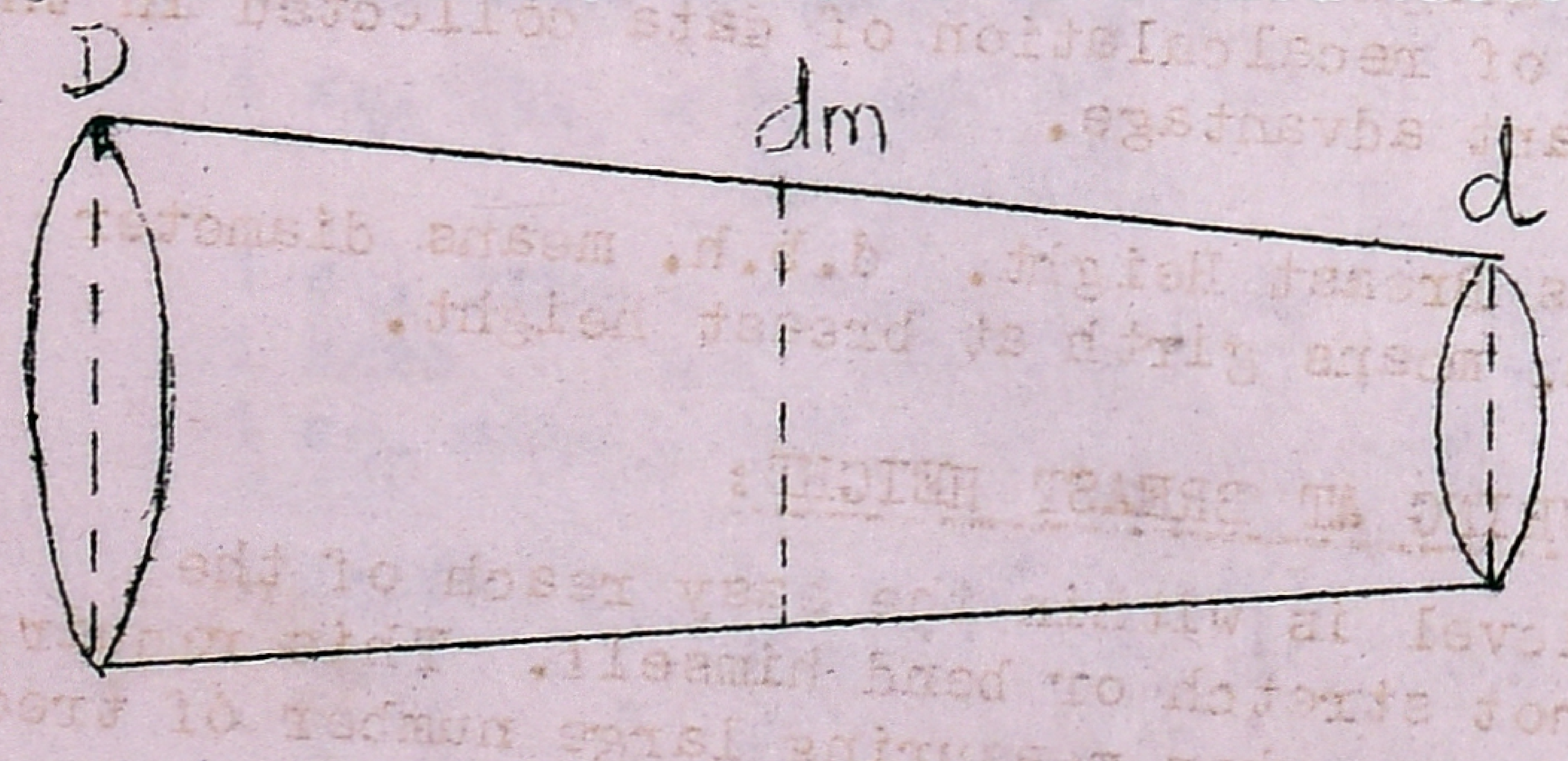
1.2 In forestry we require linear measurement while measuring the boundary of a tract of land. It is also required while measuring diameter, girth, crown width, length of bole, commercial bole, etc. Regarding the measurement of land you will study under " Forest Surveying ". The very important linear measurement in trees is the measurement of Girth and Diameter. We assume that the tree section is always circular.

2. Necessity for Girth or diameter measurement:

Diameters or girths form the basis for the calculation of the sectional areas of logs or standing trees. Volume can be found out by multiplication of sectional area and length. When inventory of growing stock has to be made, Girth or diameter has to be measured. This is the dimension with which we correlate the age, height, volume, increment of trees or crop. For all these purposes we require the measurements of diameter or girth.

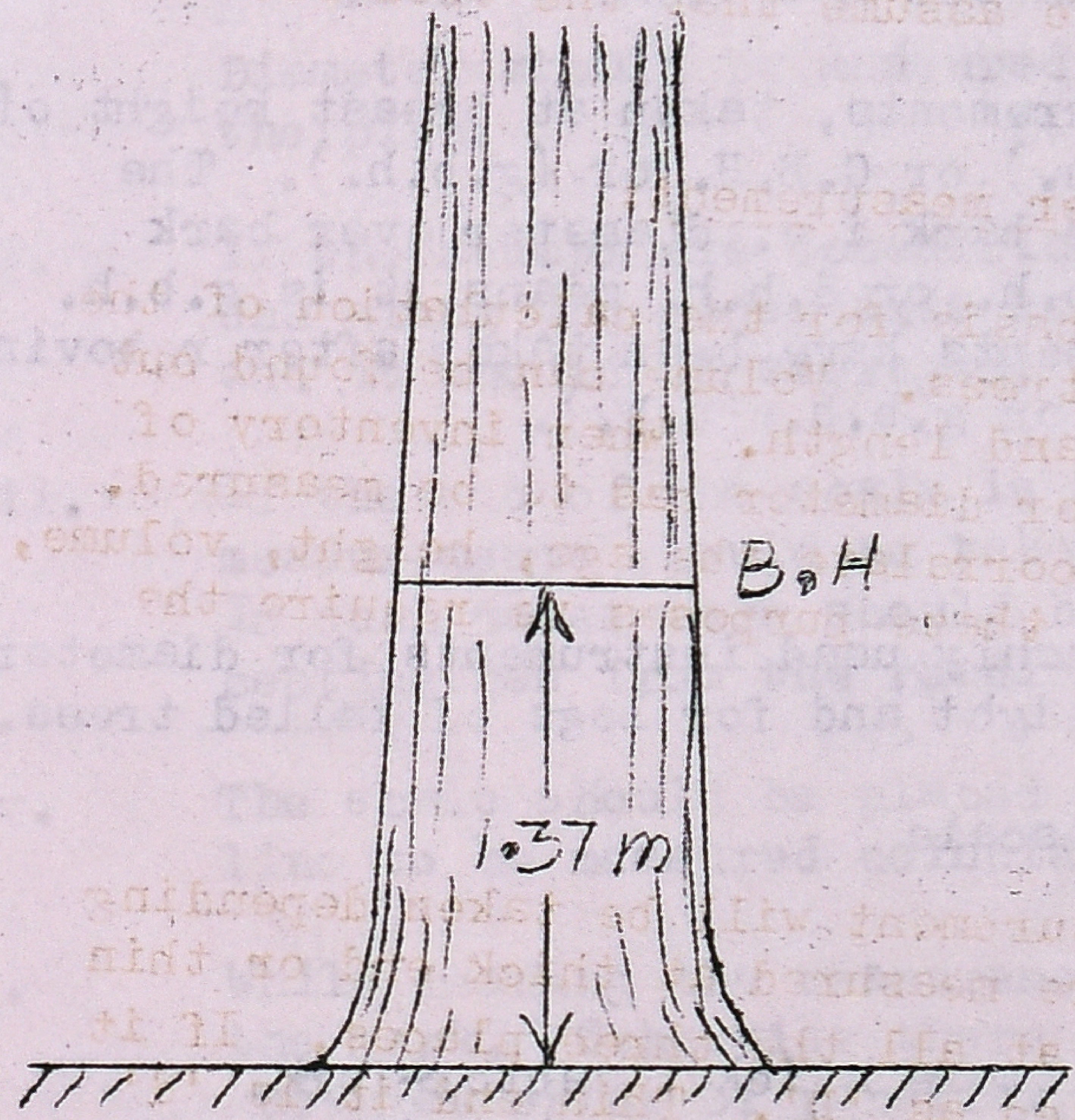
PLACE OF MEASUREMENT AND REASONS

3.1 Logs: Diameter or girth measurement will be taken depending upon the circumstances. Diameters are measured at thick end or thin end or at the middle of the logs or at all the three places. If it is measured at thick end it is denoted as 'D'. Thin end it is 'd' and middle as "dm". If logs are stacked, diameters will be taken at end cross sections. Girths of logs are taken at middle, except when they are stacked. In case of felled trees, the tree length is divided into sections and diameter or girth of each log will be measured as explained above.



3.2 Standing Trees: In this case, measurements should be taken at a standard height. It can be measured at several heights within easy reach of the man, standing on the ground. If the place is too high, the man may require a ladder. In earlier days, measurements were made at the base or stump height. But a standard place has been evolved and that is Breast-height.

4.1 BREAST HEIGHT: The diameter or girth measurement is needed to assess and compare the sizes of trees growing under varied conditions and subjected to different techniques. The comparability will suffer if measurements are taken at different heights from ground level or in different places in different occasions. We know that the trees taper from the ground level and we have different girth at different places depending upon the form of the tree. Lack of uniformity may lead to confusion, while prescribing exploitable girth or diameter, while working the forests. Hence there is a need for standardisation. Hence a point has been fixed up at vertical distance from the ground level, where such measurements should be taken. This point is known as Breast height.



4.2 Breast height is defined as almost universally adopted standard height for measuring girth, diameter and basal area of standing trees.

As the height at which measurement is taken is near the breast level, it is known as the breast height. In India, Burma, America, Union of South Africa, Malaya and some other former British countries the breast height is taken as 1.37m(4 feet 6 inches) above ground level. In Europe, United Kingdom and most other countries of the Common Wealth it is 1.3m(4 feet 3 inches). This has been recommended by F.A.O. as a standard of international adherence. But, in India, it has been decided to continue to adopt 1.37m which had been adopted as breast height for about a century, as otherwise, a change would involve lot of recalculation of data collected in the past, without any significant advantage.

B.H. or b.h. denotes Breast Height. d.b.h. means diameter at breast height and g.b.h. means girth at breast height.

5. ADVANTAGES OF MEASURING AT BREAST HEIGHT:

i. The breast height level is within the easy reach of the measurer. Hence he need not stretch or bend himself. This requires minimum strain to the measurer, when measuring large number of trees.

ii. There will be generally lot of grasses and other shrubby and thorny under growth near the base of the trees. Hence it will be difficult to take the measurements near the base and hence the undergrowth will have to be cleared. But usually the undergrowth will not be there at the breast height level and hence no clearing

need be done. This saves labour, money and time, spent in clearing the undergrowth.

iii. Most of the trees will have root-swell at the base which results in abnormal formations from the ground level. These abnormalities depend upon the species and the conditions of the ground on which the tree grows. In most cases such abnormalities disappear below the breast height level.

iv. This level is the most convenient point for taking the measurements. Hence it ensures maximum rapidity of measurement at minimum cost and time.

v. It gives a uniform point of measurement and therefore it renders a possible standardisation of diameter and girth measurement of standing trees.

vi. It is preferable to diameter/girth measurement at stump height as the stumps are never cut at uniform height and as such the standardisation will be lost. The height of stump depends upon the skill of the labour and the commercial value of the tree.

6. <u>How to Describe Measurement</u>: In Europe and America they prefer diameter measurements. Girth measurements is rare. But in India, in the past, only girth measurements was given importance. Now we are giving importance to diameter measurement also.

The diameter or girth measurements, taken at breast height of trees are known as D.B.H. or (d.b.h.) or G.B.H. or (g.b.h.). The routine measurements are taken over bark i.e. diameter over bark (D.O.B. or G.O.B.). Hence, any g.b.h. or d.b.h. means it is g.b.h. (o.b.) or d.b.h. (OB). If measurements have been taken after removing bark, it is noted as d.b.h. (u.b.) or g.b.h. (u.b.).

7. <u>INSTRUMENTS USED</u>:

7.1 Following are the most commonly used instruments for diameter and girth measurements at breast height and for logs of felled trees.

i. Foot rule or wooden scale
ii. Callipers and
iii. Tape

Though instruments like Biltmore sticks, sector-fork, pentaprism, Barr and Stroud Dendrometer, etc. are used in western countries, we do not use them in our India.

7.2 <u>Choice of Instrument</u>: depends upon

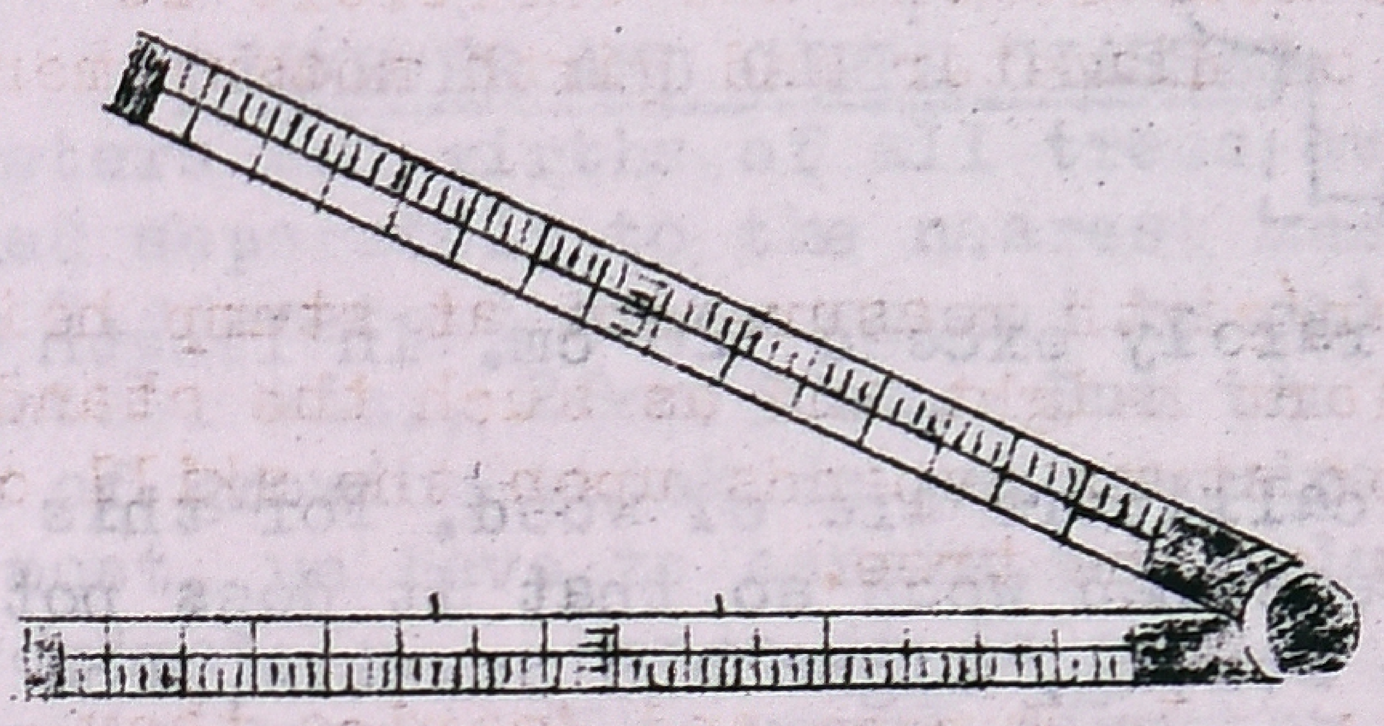
a) whether the tree is standing or felled.

b) If felled, the condition in which the logs are lying i.e. lying in the floor or stacked and

c) the degree of accuracy required.

FOOT-RULE OR WOODEN SCALE:

8.1 The wooden scale is a flat wooden piece, graduated in centimetres and millimetres. It is also of plastic. Usually its length is 30cm. and width is 2.5 cm. to 3 cm. There are foldable wooden scales also whose length will be 60cm. with a width of about 1.5cm. It can be folded at 30cm. and again at every 15cm. length. Hence it can be folded first in such a way that both lengths come side by side and then folded along its length so that the length will be 15 cm. and width will be 3 cm. These scales can be used for measuring the diameter of stumps or end sections of logs.



8.2 Rules to be observed while measuring with a wooden scale:

i. Diameter should be measured along the line passing through the pith.

ii. If the stumps are eccentric two diameters should be taken — one along the major axis and other at right angles to it and it should be averaged.

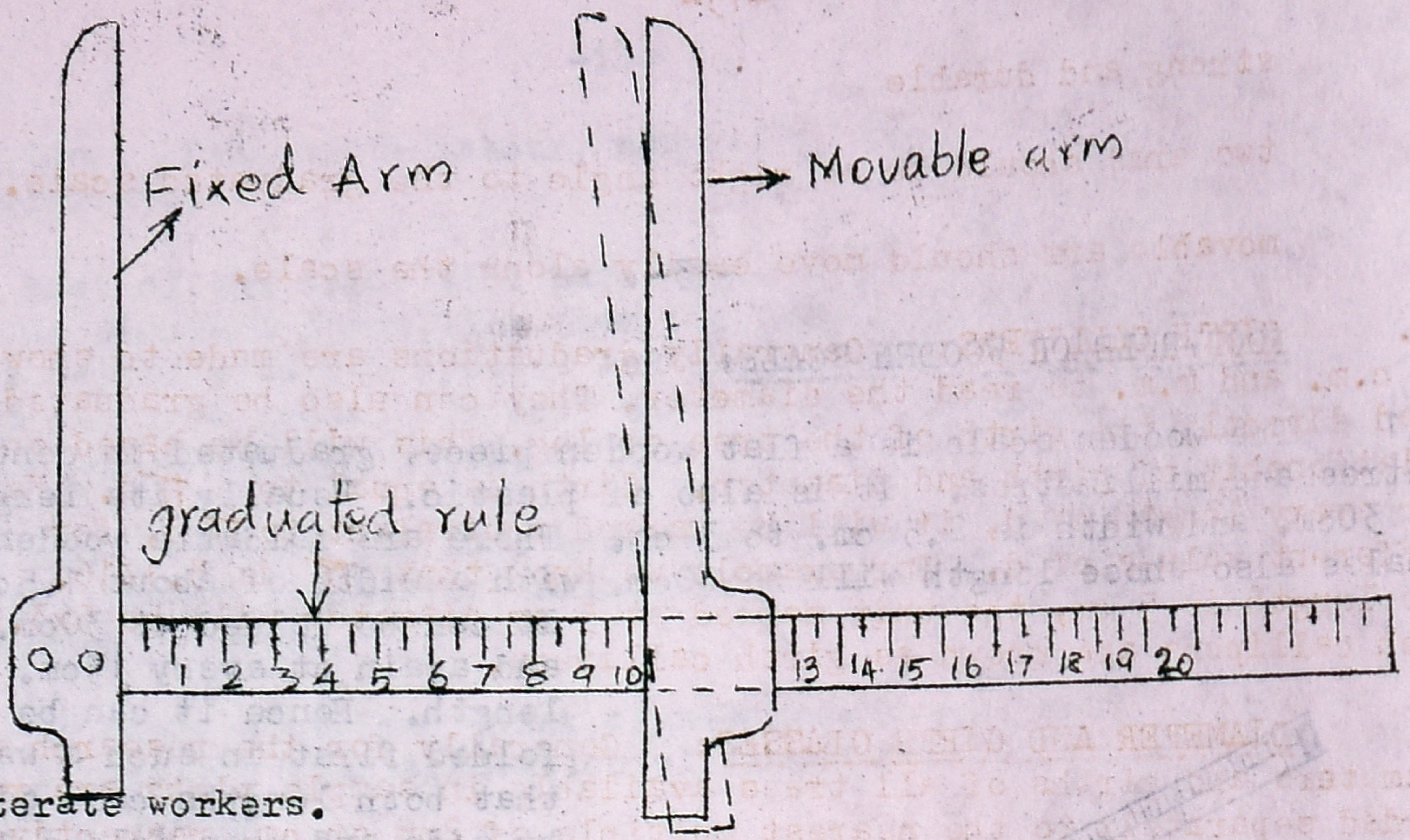
iii. If the end of the scale is worn out due to constant use, measurements should be taken from 1st or 2nd centimetre. In such cases care should be taken to deduct this one or two centimetres from the reading.

iv. The scale should be placed on edge so that the ends of the line to be measured coincide with the marks of the scale.

v. While reading the measurement, the eyes should be just above the mark. Otherwise there will be some error, which is known as error of parallax.

9. CALLIPERS are used to take the diameter measurement of standing trees as well as logs.

9.1 Construction: The callipers will have graduated rule and two arms. One arm is fixed at right angle to one end of the rule so that its inner edge lies on the starting point of the graduated rule. Other end can move along the rule parallel to the fixed arm. The length of the graduated rule and that of the arms vary depending upon the sizes of trees to be measured. The arms should be at least half the length of the rule. The rule is graduated into units - depending upon the desired degree of accuracy. If it is for research works it will be graduated to show c.m. and m.m. If it is for routine work it will be in c.m. only and diameter classes are painted in different colours so that it can be read easily by



illiterate workers.

The size of the callipers rarely exceed 120 cm. in length.

9.2 Wooden callipers: Mostly callipers are of wood. For this purpose, the wood should be well seasoned wood so that it does not warp or shrink. The wood should be strong, light and durable. The edges may be lined with brass. Seasoned teak is the best wood.

Gmelina arborea and Dalbergia sissoo have also been found to be fairly good. In the case of wooden callipers, the movable arm may get jammed - particularly in humid condtions - due to absorption of moisture by the wood. Hence, the slot of the movable arm in which the scale arm fits should be of a size that avoids jamming. It should not be too big. Hence the slot will be made oblique so that arm can be tilted inwards but not outwards.

9.3 Metal Callipers: Generally metal was not preferred because of their weight and rigidity. But callipers made of Aluminium alloy are in use now. They are not heavier than wood. They can be kept clean and maintained.

9.4 Types of Callipers: There are many types of callipers, used for measurements.

a) Friedrich's calliper (already described)

b) Flurry calliper - graduated arm wooden and brass - bound; fixed and movable arms of aluminium; available in lengths of 80 cm, 60cm and 35cm.

c) Fommes Calliper: All aluminium - available in lengths of 80cm, 60cm and 35cm.

Indian Aluminium callipers are available in 50cm, 75cm and 100 cm lengths, graduated to show c.m. and m.m.

10. Qualities of a Good Calliper: A good calliper should be

a) sufficiently light so that it does not make the measurer tired

b) strong and durable

c) two arms should be at right angle to the graduated scale.

d) movable arm should move easily along the scale.

11. GIRTH CALLIPERS: Generally graduations are made to show c.m. or c.m. and m.m. to read the diameter. They can also be graduated to read directly the girth of the tree or log. This will be based on the relationship of girth and diameter. Girth is equal to πd. Hence for every length of d, it will be marked equivalent to π d, for different values of d. For example we know that π is 3.1416. If the length is 5 cm, the unit marked at 5 cm diameter will be 5x3.1416. Such callipers are known as girth callipers.

12. DIAMETER AND GIRTH CLASSES: Generally for the research works, diameters and girths of all trees available in sample plots are recorded separately to the nearest multiple of 2mm or cm. respectively. When 2 diameters are measured by callipers they are recorded one over the other viz., 28cm/30cm. But the routine forest works like enumeration of growing stock do not require a high degree of accuracy. At the most, we have to assess the volume of a large number of trees approximately. Hence it is enough if the diameter class or girth class is known. The usual diameter classes used in India are 2cm, 5cm and 10cm. The 2cm diameter class will have a difference of 2cm. Eg.: 0-2, 2 to 4, cm4 - 6, cm6-8, etc. The 5 cm diameter class will have a difference of 5cm. Eg.: 0-5cm, 5-10cm, 10-15cm, etc. We were using the 1", 2", and 4" diameter classes previously. The diameter classes grouping depends upon the rate of growth of the particular species and the size it attains on maturity. Following diameter classes are recommended.-

a) Trees attaining maturity under 30cm d.b.h. : 2cm class or 1 inch class.

b) Trees attaining maturity at 30cm to 50cm d.b.h. : 5cm class or 2 inch class

c) Trees attaining maturity more than 50cm d.b.h. : 10cm class or 4 inch class.

13.1 GIRTH CLASSES: The usual girth classes used in India are 30cm, 15cm and 5 cm for large, medium and small-sized trees.

13.2 COLOURED CALLIPERS: In such cases it is enough if the callipers are graduated the diameter classes or the corresponding girth classes. Hence only the limits of the classes will be marked in the calliper. In India, lot of illiterate mazdoors are employed for the forest works for the purposes of enumeration. Hence they may not be able to read and find the exact measurements. Hence the calliper will be graduated by colouring the inter-spaces between the diameter classes, so that each colour will represent one diameter class. When the enumeration works are progressing, it is enough if the labourer speaks out the colours. The forester will record the correct diameter class in the enumeration book. Such callipers that show different colours for different diameter classes are known as coloured callipers. Following colours are usually given for 10cm diameter classes.

Diameter class in metric system	Diameter class in British system	Colours
0 - 20cm	0 - 8 inch	Blank
20 - 30	8 - 12 "	Green
30 - 40	12-16 "	Red
40 - 50	16- 20 "	Yellow
50 - 60	20- 24 "	Black
60 - 70	24- 28 "	White
70 - 80 and above	28- 32 and above	Blue

Similar colouring can be done in tapes also.

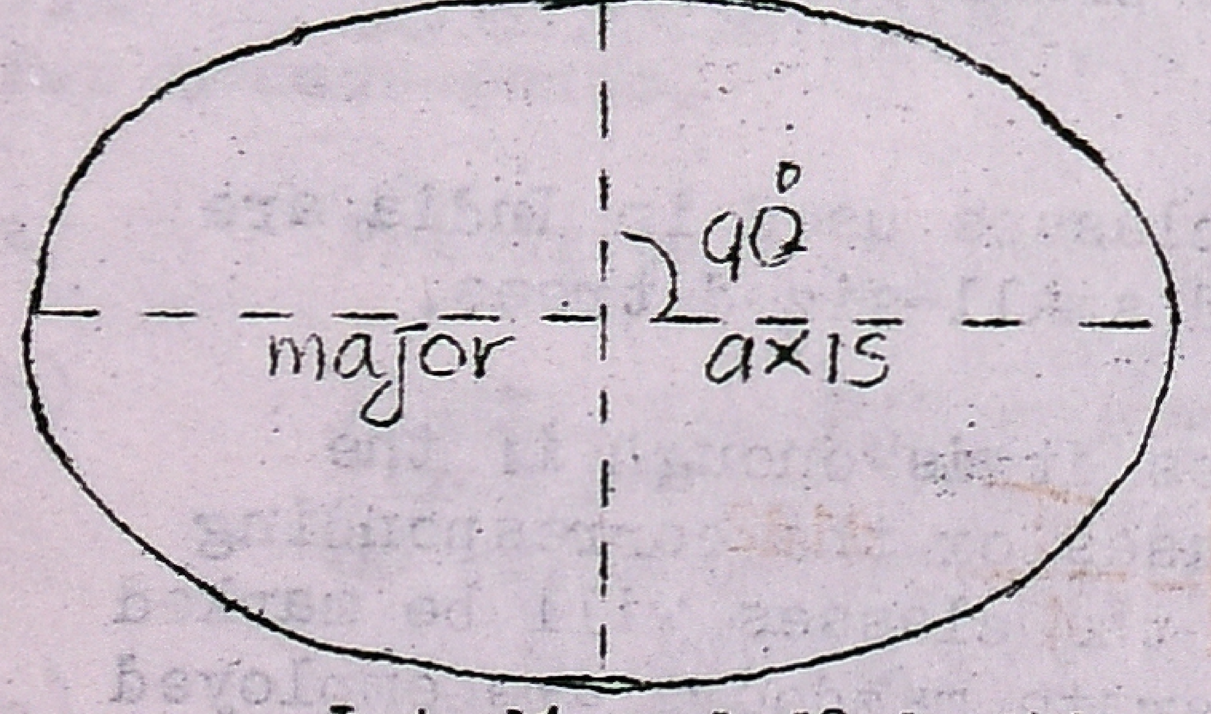
14. Method of use of Callipers: The handles of both the arms are held in 2 hands. The movable arm is tilted inwards so that it can move. Thus both the arms are separated. Then the calliper is kept so that the tree comes in between the two arms. When the tree touches the graduated rule, the movable arm is brought inwards. Now the tree will touch the movable arm in one side and fixed arm on the other side. Now the movable arm is brought in perpendicular position to the graduated rule. It will then be pressed gently so that the lose bark will be squeezed out. Now the arms will be in close touch with the tree. The diameter is read off on the scale.

15. Precautions in Use: Errors may be avoided by observing the following precautions, when diameters are measured by callipers.

a) Movable arms should be well opened before placing the calliper on the tree. It should not be forced on the tree.

b) Reading must be taken before the calliper is removed from the tree.

c) Suppose the cross section of the stem is more or less elliptical, atleast 2 diameters should be measured - one along the major axis and another along the minor axis, which, will be at right angle to the major axis. The average of the two measurements will be diameter. If only one measurement is taken, it may be over-estimated or under-estimated depending upon the axis chosen. Now let us see error involved in calculating the basal area.



Let d1 and d2 be the diameters of elliptical cross section of the tree. The true area of the ellipse is $\pi/4 \times d1d2$ (we know that area of circle is πr^2 and $r = d/2$).

i. The diameters may be averaged and area may be calculated. In this case average diameter will be $\frac{d1 + d2}{2}$. Then area will be $\frac{\pi}{4}\left(\frac{d1 + d2}{2}\right)^2$.

The error involved in this will be $\frac{\pi}{4}\left(\frac{d1+d2}{2}\right)^2 - \frac{\pi}{4} d1d2$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2+2d1d2}{4} - d1\,d2\right\}$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2+2d1d2-4d1d2}{4}\right\}$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2-2d1d2}{4}\right\}$

i.e. $\frac{\pi}{4}\left\{\frac{d1-d2}{4}\right\}^2$

i.e. $\frac{\pi}{16}(d1-d2)^2$

ii. Other method is: find the basal area of d1 and the basal area of d2 and then average the basal area. Thus

Basal area of d1 $= \pi\frac{d1}{2} \times \frac{d1}{2}$ i.e. $\frac{\pi d1^2}{4}$

Basal area of d2 $= \frac{\pi d2^2}{4}$

Total will be $= \frac{\pi d1^2}{4} + \frac{\pi d2^2}{4}$ i.e. $\frac{\pi d1^2 + \pi d2^2}{4}$

Average will be $\frac{\pi d1^2 + \pi d2^2}{4 \times 2}$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2}{2}\right\}$

Hence error will be $\frac{\pi}{4}\left\{\frac{d1^2+d2^2}{2}\right\} - \frac{\pi}{4} d1d2$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2}{2} - d1d2\right\}$

i.e. $\frac{\pi}{4}\left\{\frac{d1^2+d2^2-2d1\,d2}{2}\right\}$

i.e. $\frac{\pi}{4}\left\{\frac{d1-d2}{2}\right\}^2$

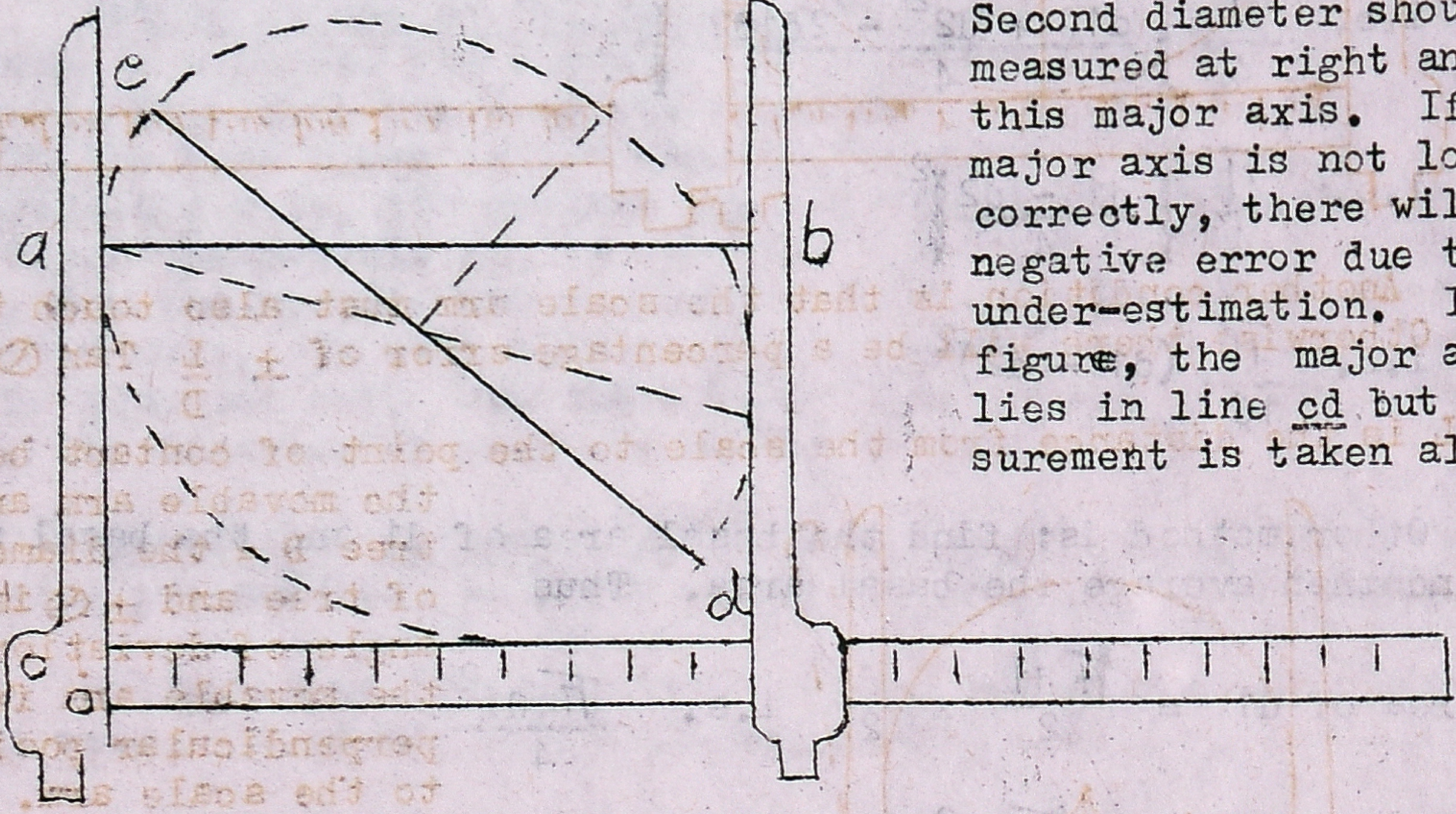
i.e. $\frac{\pi}{8}(d1-d2)^2$

Hence the error in method i, i.e. calculating the average diameter and then calculating basal area the error is $\frac{\pi}{16}$ $(d1 - d2)^2$ and

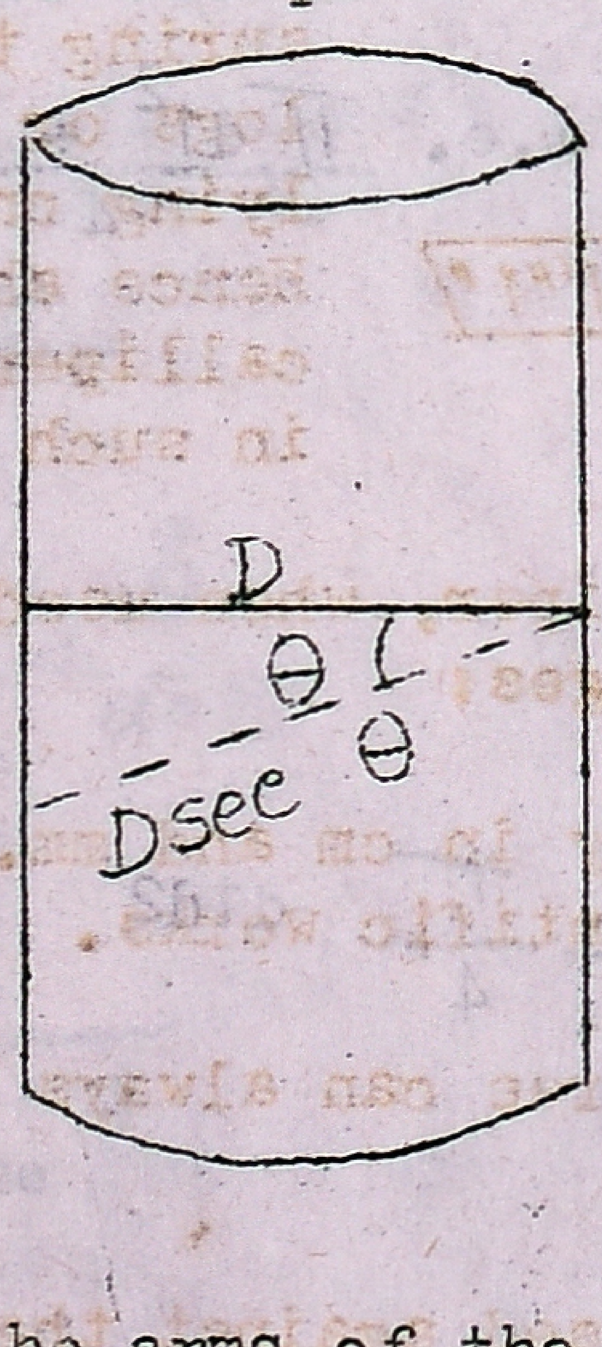
in method ii, the error is $\frac{\pi}{8}$ $(d1 - d2)^2$.

Hence the error in both cases are positive. But the error in method ii, is double the error involved in method i. Hence method i, is a closer approximation to the actual area of the ellipse.

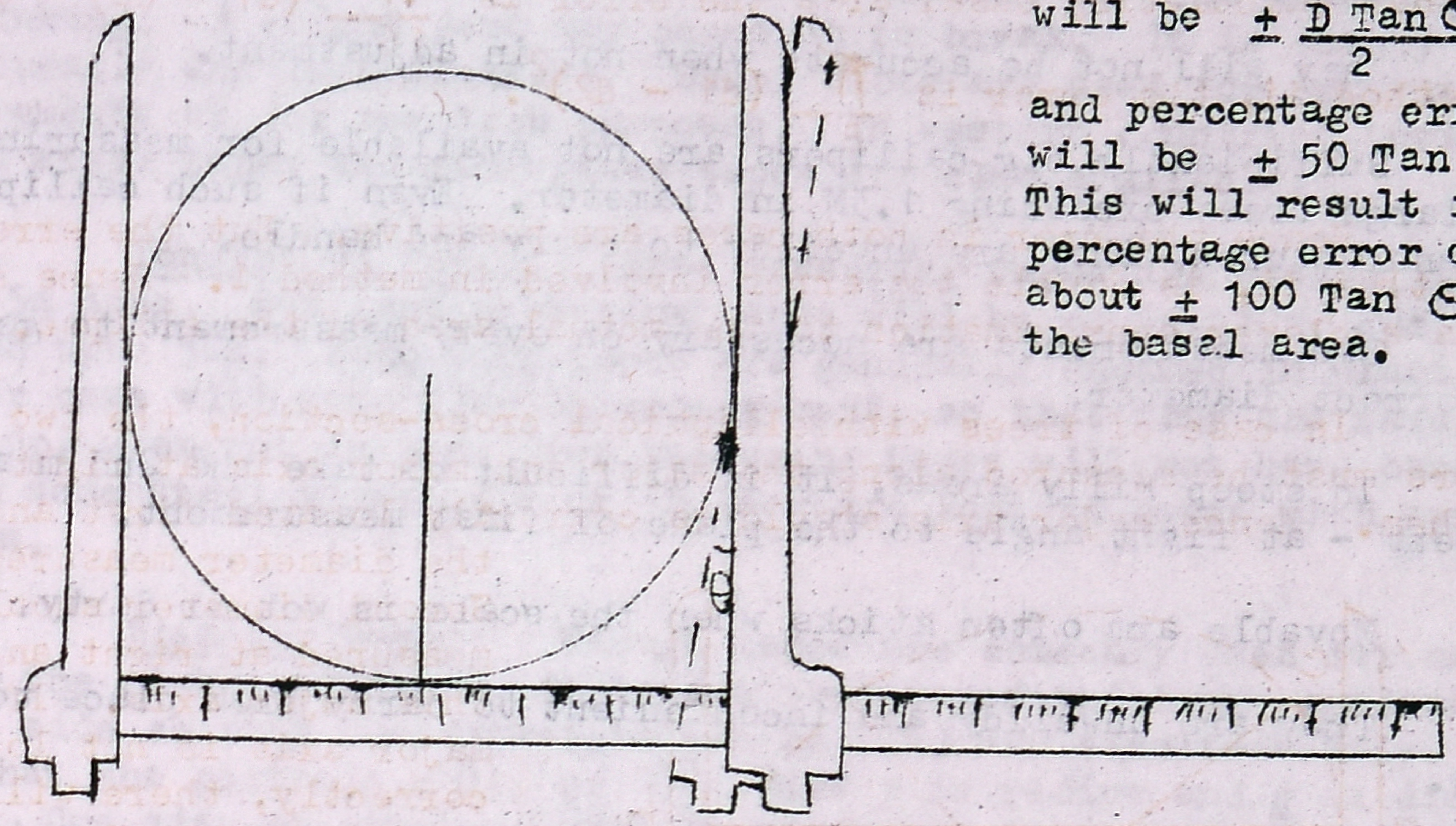
d) In case of trees with elliptical cross-section, the two diameters must be measured along the major and minor axis at right angle to them. Hence major axis should be correctly located first and then the diameter measured. Second diameter should be measured at right angle to this major axis. If the major axis is not located correctly, there will be negative error due to under-estimation. In the figure, the major axis lies in line cd but measurement is taken along ab.



e) Callipers should always be placed at right angle of the axis of the tree. If the plane of calliper is inclined by an angle of Θ to the horizontal plane of the tree with Diameter D, the measured diameter will be D (see Θ). Hence the error will be D see Θ - D i.e. D (see Θ - 1). The percentage error will be 100 (See 0 - 1). Hence the percentage of error depends upon the angle of inclination. This is a positive error i.e. over-estimated.

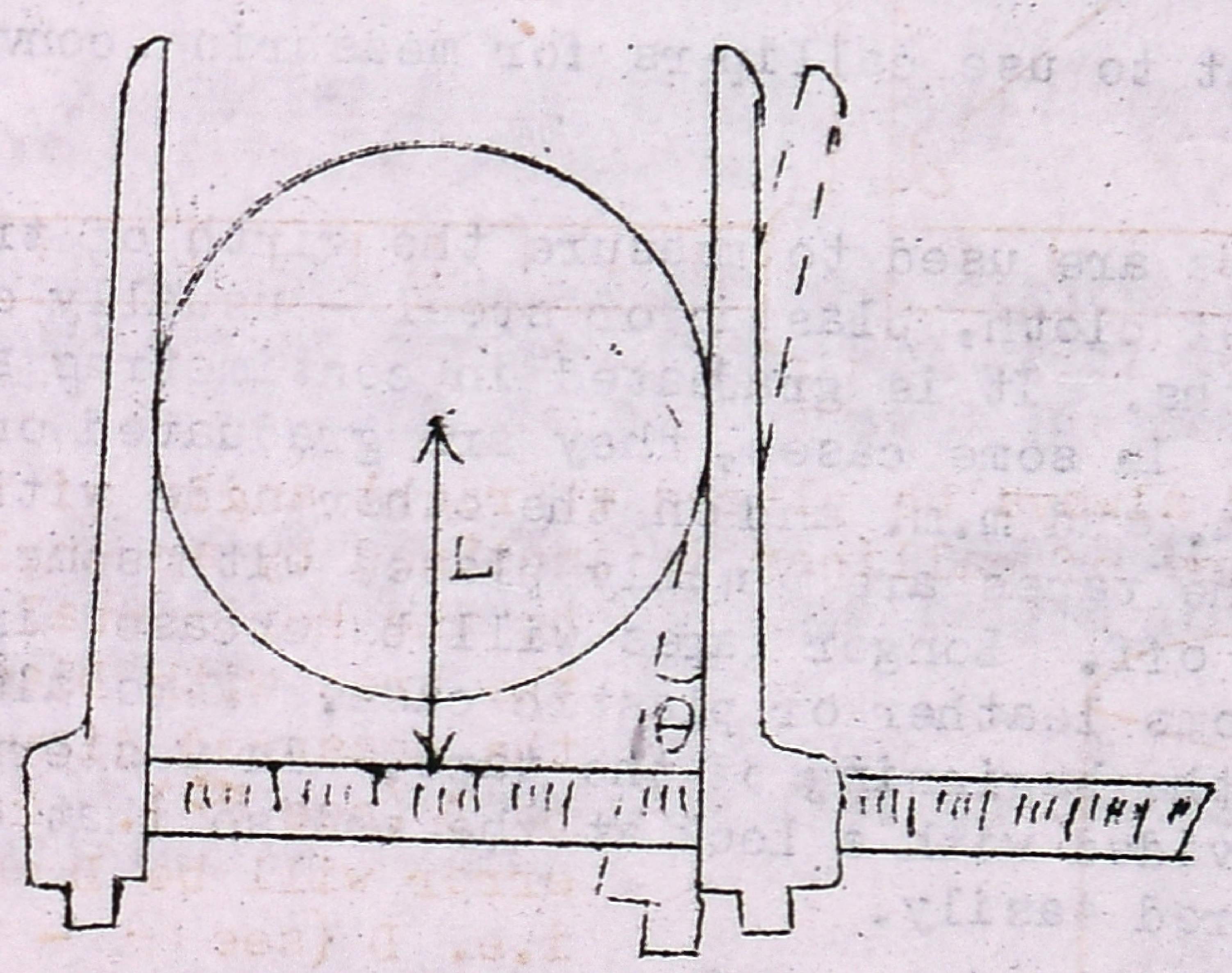


f) Both the arms of the calliper should be in contact with the tree. The movable arm should be at right angle to the graduated scale. If it is not at right angle to the scale arm, and deviates by an angle by ± Θ degrees, there will be an error in the measured



diameter. The error will be $\pm \frac{D \tan \theta}{2}$ and percentage error will be $\pm 50 \tan \theta$. This will result in a percentage error of about $\pm 100 \tan \theta$ in the basal area.

g) Another condition is that the scale arm must also touch the tree. Otherwise there will be a percentage error of $\pm \frac{L}{D} \tan \theta \times 100$. Where L is the distance from the scale to the point of contact between the movable arm and the tree D = the diameter of tree and $\pm\theta$ is the angle of deviation of the movable arm from the perpendicular position to the scale arm. This error is very common, particularly when measuring the diameter of logs or felled trees lying on the ground. Hence short armed callipers should be used in such cases.



16. Advantages of Callipers: Calliper, when used for diameter measurements, have the following advantages:

i. Diameter can be measured directly in cm and mm. Hence this measurement may be used for precise scientific works.

ii. The point of arms touching the tree can always been seen by us. Hence any irregularity is avoided.

iii. If both the arms are firmly pressed against the tree bole, the loose swollen bark is crushed out and irregularity from this source is avoided.

iv. There are positive and negative errors. Hence they may neutralize and give more accurate results.

v. Even unskilled labourer can use coloured calliper.

vi. Measurements can be taken quickly.

vii. Any single individual can measure even big trees without assistance.

17. Disadvantages of Callipers:

i. They will not be accurate when not in adjustment.

ii. Sufficiently big callipers are not available for measuring very large trees exceeding 1.3M in diameter. Even if such callipers are manufactured, they are unweildy to carry and handle.

iii. Two measurements are necessary on every measurement to get the correct diameter.

iv. In steep hilly areas, it is difficult to take the 2nd measurement - at right angle to the plane of first measurement.

v. Movable arm often sticks when the scale is wet or dirty.

vi. They are unweildy and inconvenient to carry from place to place.

vii. Measurements depend upon the points of measurement. This varies from person to person and at different times of measurement. Hence unless a cross mark is painted on the tree to indicate the point of measurement, there will be variations.

viii. It is inconvenient to use callipers for measuring converted logs.

18. TAPE: Generally tapes are used to measure the girth of trees and logs. Tapes may be of cloth, plastic or steel - usually of 1.5cm wide and of varying lengths. It is graduated in centimetres and millimetres on one side. In some cases, they are graduated on both sides - one side with c.m. and m.m. and on the other side with inches and feet. The ends of the tapes are usually plated with some metal to prevent their tearing off. Longer tapes will be encased in some cover by winding it in some leather or plastic case. Here also there will be a metal ring at the beginning of the tape. In western countries, the tapes are provided with a hook at the end so that even large trees can be measured easily.

19. Types of Tape: There are three types of tapes. They are i) cloth or linen ii) metallic iii) steel.

i. Cloth or Linen: They are made of cloth or linen band, usually painted with about one c.m. wide. Painting is done to give a better look and to protect the tapes from the influence of water. They are of varying lengths and graduated in cm and mm or cm and metres. They are cheap but not durable. Longer tapes are encased in a leather case. It is liable to stretch, twist and tangle in use - shrink when wet and blow about when used in windy weather. Hence they are affected by fluctuations in length due to expansion in use. Its use should be restricted.

ii. Metallic tapes are made of water-proofed fabric, inter-woven with very fine brass or copper wires to prevent stretching and twisting. As it is reinforced with metal wires, it is known as metallic tape. They are painted with durable paint and hence are more durable and dependable. This is far better than cloth or linen tapes. But with prolonged use, it stretches permanently. But it is light, flexible and durable.

iii. A steel tape is of steel ribbon constructed and divided as a cloth tape and is used for accurate works. It is of varying lengths. It should be carefully used to prevent it from twisting and kinking. A slight jerk may cause it to break. It is costly but less durable and less flexible. Steel tapes are used for accurate measurements as for research purposes. In western countries, nylon coated steel tapes and fibreglass tapes are also available.

20. Lengths of Tapes: Tree measuring tapes are generally of 3m or 5m long. But land measuring tapes will be of 5m, 10m, 20m,30m or even upto 50m. Such long tapes are generally encased in plastic or leather case with some winding arrangement, so that they are safely wound up, when not in use. Tree measuring tapes will not have case though some steel tapes of 2 or 3m long are kept in cases with spring devices.

21. Diameter Tapes: Though tapes are commonly used for measuring the girths of trees, there are some tapes which are graduated on one side so that the diameters can be read off simultaneously. We know that the girth is $2\pi r$ or πd where r is radius and d is diameter. One side of the tape will be graduated in mm and cm to read the girth. Another side of the tape will be graduated using the relationship of $g = \pi d$. Hence for every 3.1416cm, centimetre divisions will be marked. This is made with the assumption that the cross section of trees or logs are circular which is not always the case.

22. Precautions in using a Tape: To avoid errors, following precautions should be observed:

i. Old tapes would have been stretched or their ends would have been broken or damaged. The old steel tapes would have been rusted. Hence they should not be used for measurements.

ii. If the ends are broken or damaged, measurement should be taken from 2nd or 3rd c.m. and this length should be deducted from the total measurement.

iii. It should always lie flat on the tree or log and should never be allowed to twist.

iv. It should be in a plane perpendicular to the axis of the tree. Otherwise its girth will be over-estimated. Consequently the basal area is also over-estimated depending upon the angle of displaced tape.

v. Climbers and other growth should be cut before swinging the loose end of the tape around the tree.

vi. After swinging round the tree, the end of the right hand of the measurer should be brought under the starting point of the tape on the left hand so that the correct reading can be seen and recorded.

vii. The tape should be taken care of. It should not be allowed to trail on the ground or get entangled in thorny bushes. It should not be rolled when wet or twisted. It can be cleaned with a dry cloth before rolling.

23. Advantages of Tape:

i. Convenient to carry.
ii. Does not require constant adjustment.
iii. One measurement is sufficient.
iv. When the logs are lying on the ground, it may not be possible to measure the logs with a calliper. In such cases tapes may be used.
v. Errors are always positive and systematic. Hence any adjustment can be done easily.
vi. Tape runs around the whole circumference of the tree whereas calliper touches only three points on it. Hence tape measures the size of the tree better than a calliper.
vii. Callipers may give different reading for the same tree when measured by different men. But tapes do not suffer from this defect. Hence their readings are more consistent.

24. Disadvantages of tape:

i. In case the tree has rough bark, the tape exaggerates the diameter or girth measurement.

ii. Progress in measurement is slower, particularly in areas with dense shrub growth.

iii. Since the tape has to be swung around the tree, some times it is not in a plane at right angle to the axis of the tree.

iv. In case of large trees, two men may be required to measure.

v. The tape, being elastic, is subjected to give wrong measurements.

25. Methods in practice: Depending on the circumstances, girth or diameter will be measured. For ordinary purposes, girths are taken whereas for research purposes, diameter measurements are taken. Sectional areas are easily calculated with diameter. Hence it is better that diameter tapes are put to use for all purposes.

26. Comparison between Callipers and Tapes: We have already discussed the advantages and disadvantages of callipers and tapes in paragraph 16, 17, 23 and 24. Both the instruments are used for measuring girth or diameter of logs and trees with the aim of finding out their sectional area and from them the volume. Let us compare the errors involved in using the above instruments.

i. When taking the girth or diameter measurements, we assume that the cross section of the tree is circular. The error in area involved due to this assumption has already been discussed in para 15. But the error in basal area calculated from taped girth is slightly more than that calculated from callipered diameter, when calculated with the formula

$$\pi \frac{(a + b)^2}{2}$$

ii. Using callipers is difficult due to the following reasons.

a) Orientation of the major axis is difficult as it is difficult to locate the major axis. Hence there is under-estimation of diameter.

b) After fixing major axis, there is a difficulty in fixing up minor axis which should be at right angle to the major axis.

c) It is difficult to keep the sliding arm at right angle to the scale arm. Even a slight deviations of 2° from the right angle position results in an error of about 3.5% in basal area.

d) The scale of the calliper will not touch the tree in most of the times.

e) It is difficult to keep the plane of the calliper at right angle to the axis of the tree at the time of measurement. A deviation of 10° involves an error of 1.54% in diameter measurement and about 3.1% in basal area calculated from it.

The number of sources of errors in girth measurement by tape is comparatively much less. Following will be the usual errors in tape.

a) Displacement of the tape from the horizontal, causes an error in girth and consequently in basal area. But the percentage of error is only half of that involved by a calliper.

b) Error involved due to elasticity of tape is negligible.

c) Error involved due to expansion of tape is also negligible.

Hence it is clear that using a tape gives much less errors than by a calliper.

iii. The girth is approximately 3 times the diameter. Thus one c.m. error in girth will give only 1/3cm. error in diameter and hence that much of error in the basal area. Hence less error in girth measurement, by tapes.

iv. It has been established that girth by tape ensures more consistent results than that of calliper for successive volume measurements in a sample plot. It has been proved by Scherer that the proportion between the error involved in use of calliper and tape is 21 : 1. Hence calliper measurements are not dependable as sometimes, the same man with the same calliper, measures the same tree and gets different results due to lack of concentration, fatigue, etc.

v. Errors in tapes are positive and can be easily standardised. But it is not the case in callipers as the errors are unsystematic and subject to personal factors.

vi. Tape measurements are simpler; do not require calculations as they do not require 2 measurements; easy to take.

vii. Tape is easy in case of felled trees and logs lying on the ground.

viii. It has been found by the Research workers that the time consumed for taking measurements with tape and calliper is the same for research works. But calliper measurements are quicker in routine forest works. American research workers like Mr. Ardle, Condy and Kravah and Chaturvedi in India have found out that girth by tape is far better than calliper measurement for sample plots in the interest of accuracy.

Thus, tapes and callipers have their own advantages and disadvantages. Callipers are more accurate. But its measurements are susceptible for errors, Tapes are time consuming. Hence choice between tapes and callipers depends upon the kind and circumstances of work.

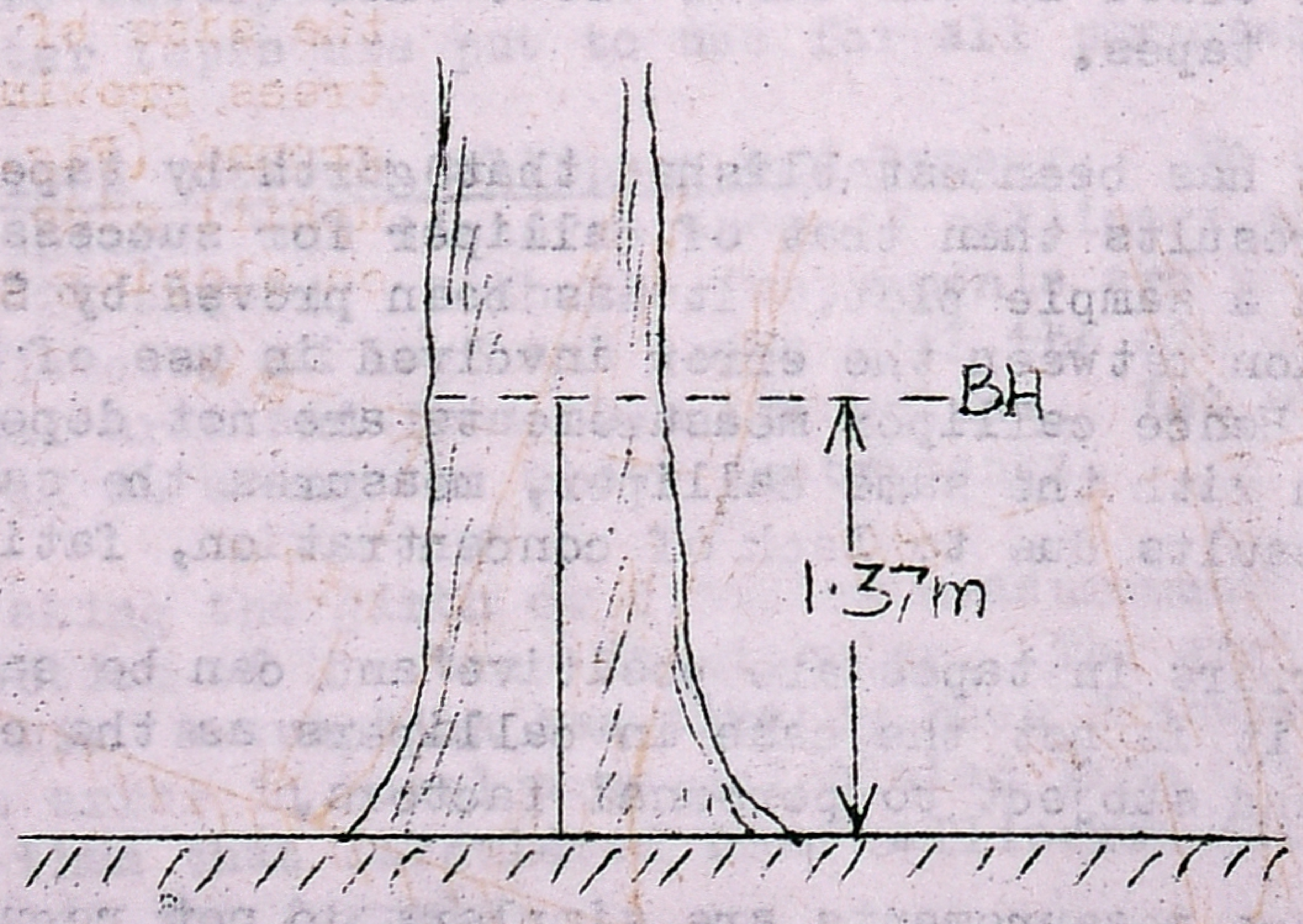
27. Method of checking Callipers and Tapes:

Accuracy of calliper and tape will have to be checked before using them. Both can be checked with steel tape. In callipers, the graduations should also be checked with steel tape. The calliper may be opened out and the distance between the ends of the arms may be measured with a steel tape and thus compared with the reading on the scale. Both should be correct if the sliding arm is perpendicular to the scale. In case of tapes celibrations should be checked with steel tape. It should be checked if any torn out portion has been stitched anywhere so as to shorten the length.

28. Standard Rules Governing Breast Height Measurements:

Following are the standard rules governing breast height measurements with tape or calliper.

i. Measurements should be taken at breast height i.e. 1.37 metres from ground level. (Fig.1)



F. 1

ii. The breast height point should be clearly marked on the tree by intersecting vertical and horizontal lines of 12cm long and painted with white paint. This is referred to as cross-mark (Fig.2).

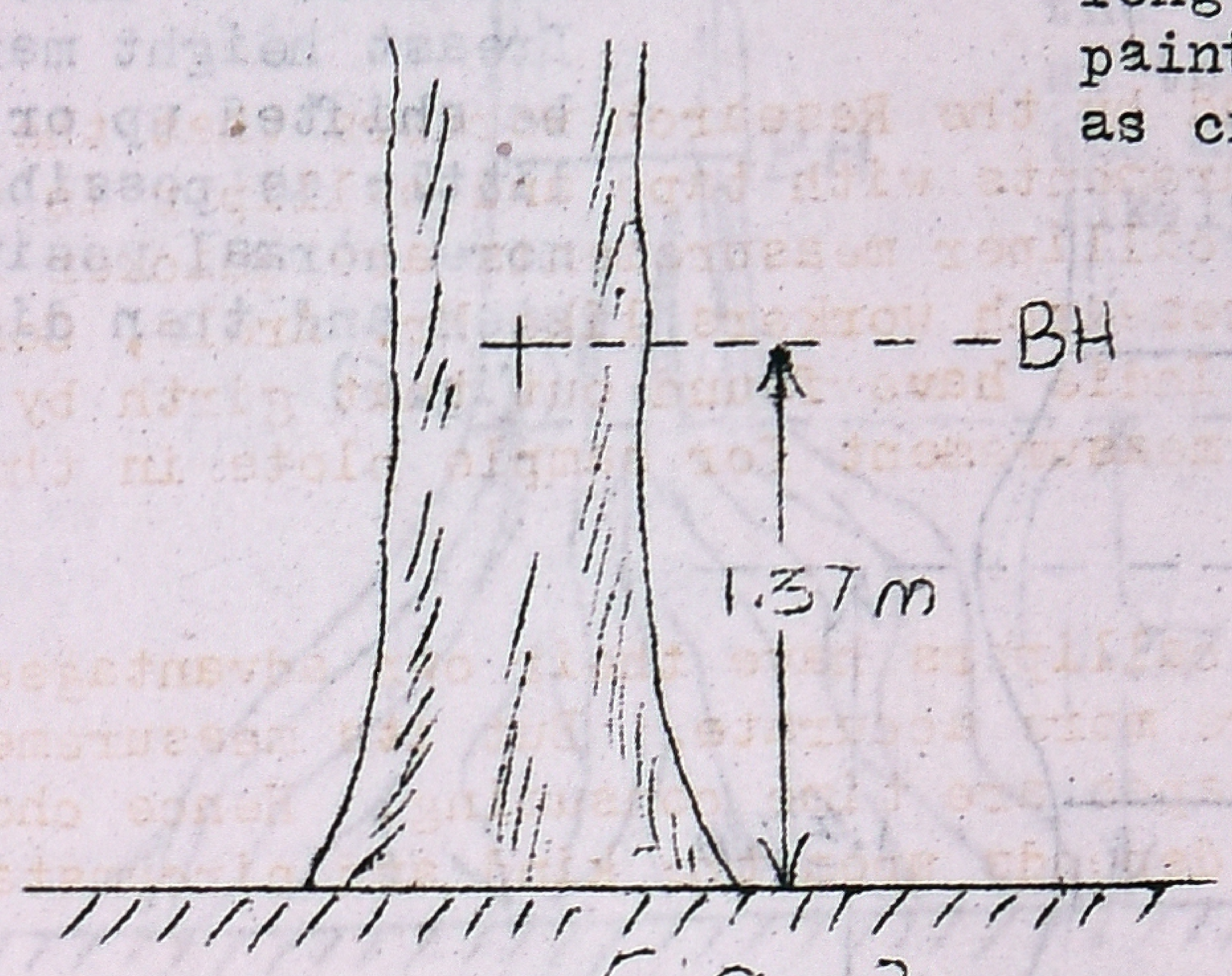


Fig 2

iii. On sloping ground, the diameter at breast height should be measured on the uphill side, after removing any dead leaves, needles, etc. lodged there. (Fig.3)

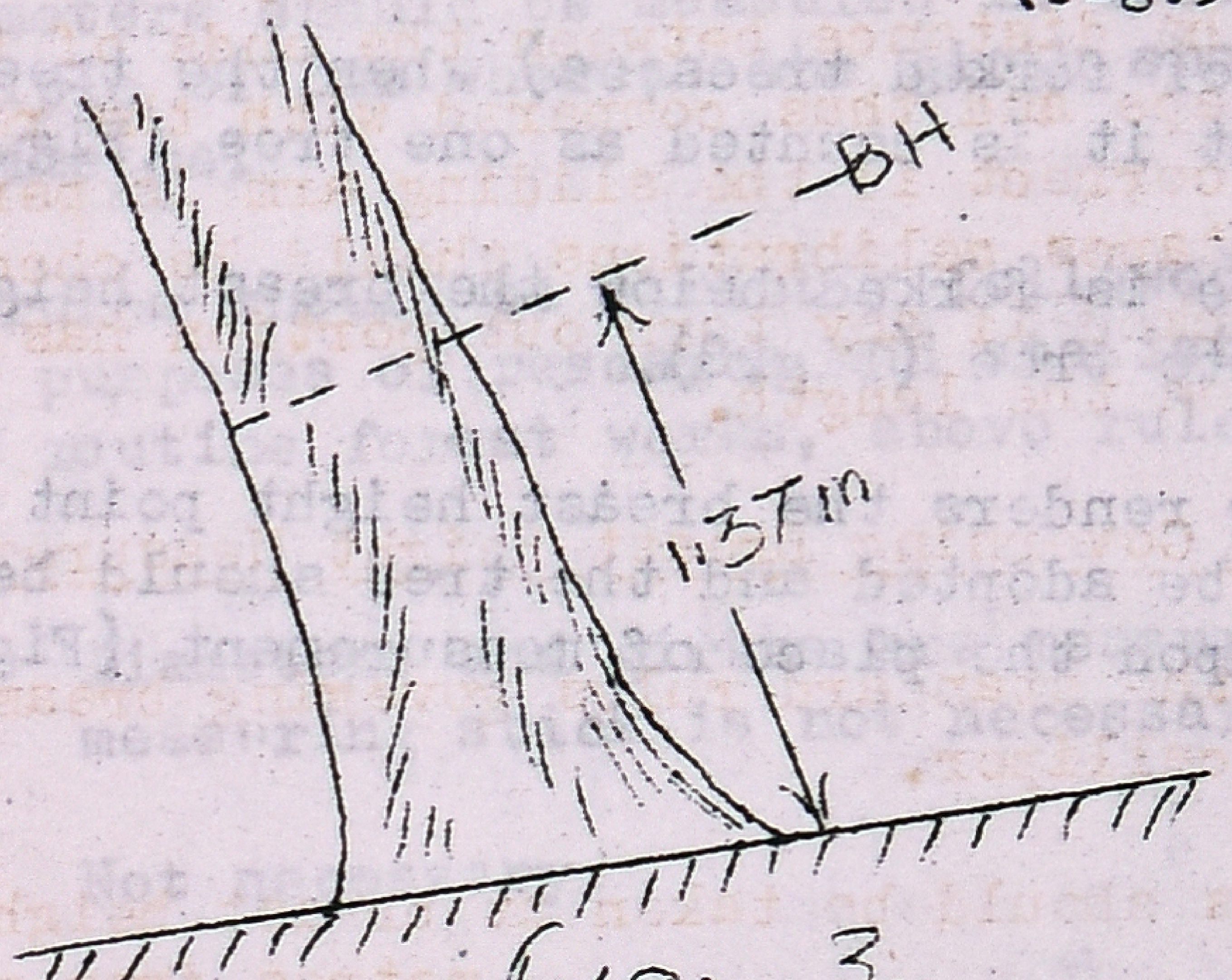


Fig. 3

iv. In case the tree is leaning, dbh is measured along the tree and not vertically on the side of the lean for trees growing on the flat ground (Fig.4) and on the uphill side for trees growing on sloping ground (Fig.5)

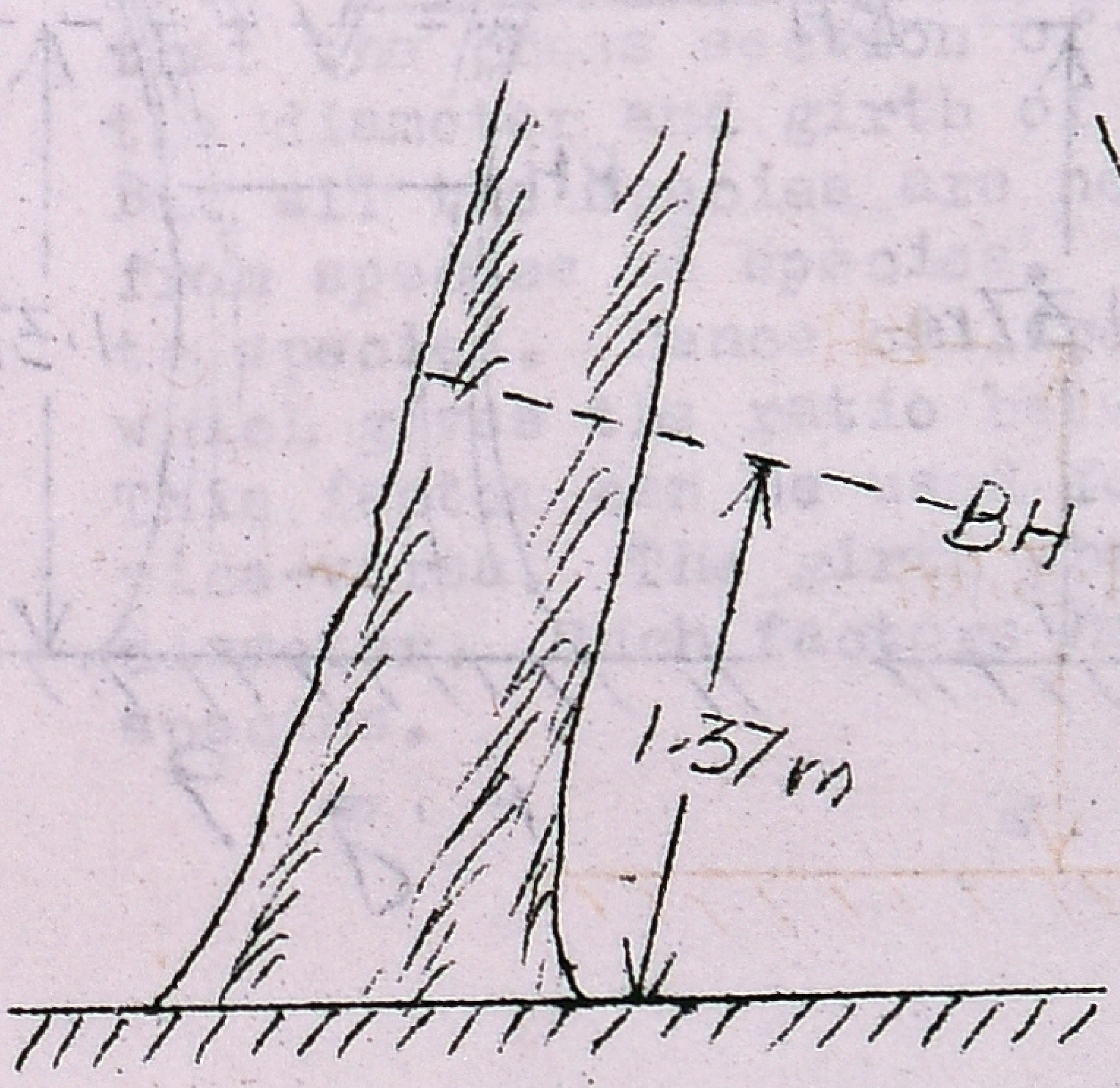


Fig 4

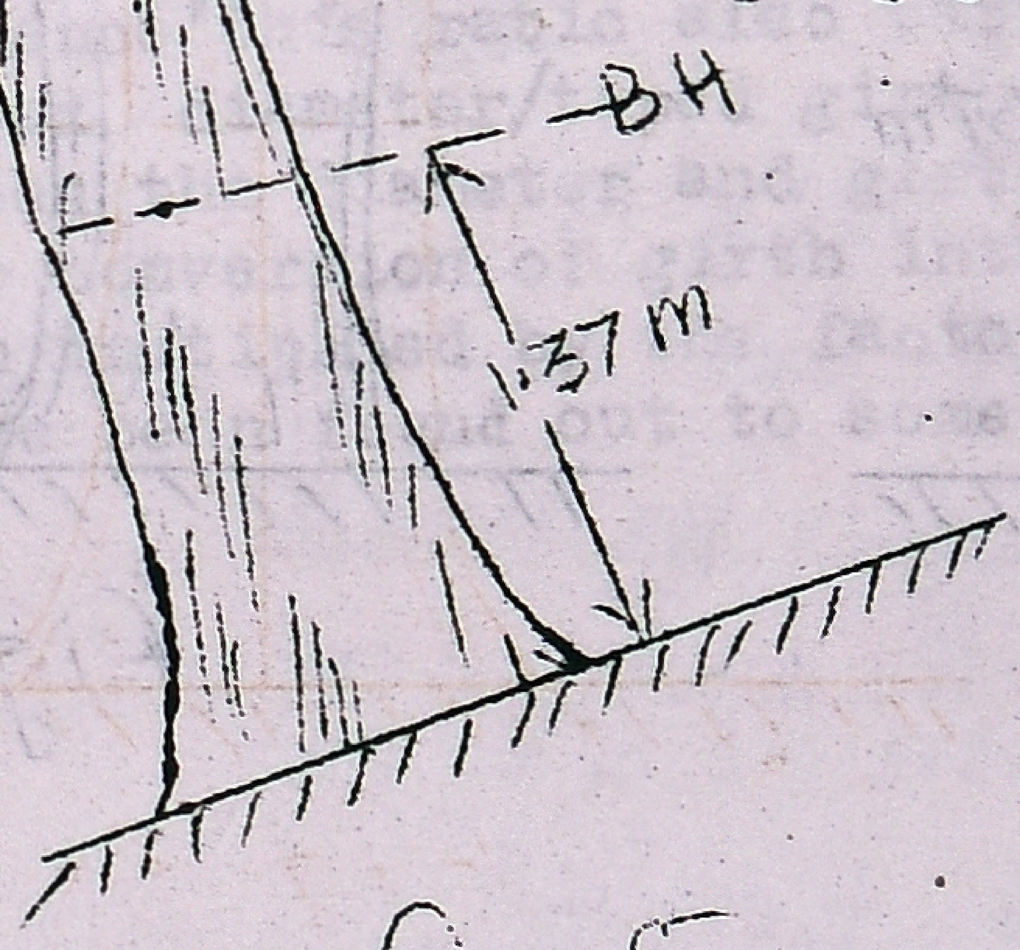


Fig 5

v. The d.b.h. should not be measured at 1.37m. if the stem is abnormal at that level. Breast height mark should be shifted up or down as little as possible to a more normal position of the stem and then diameter measured. (Fig.6)

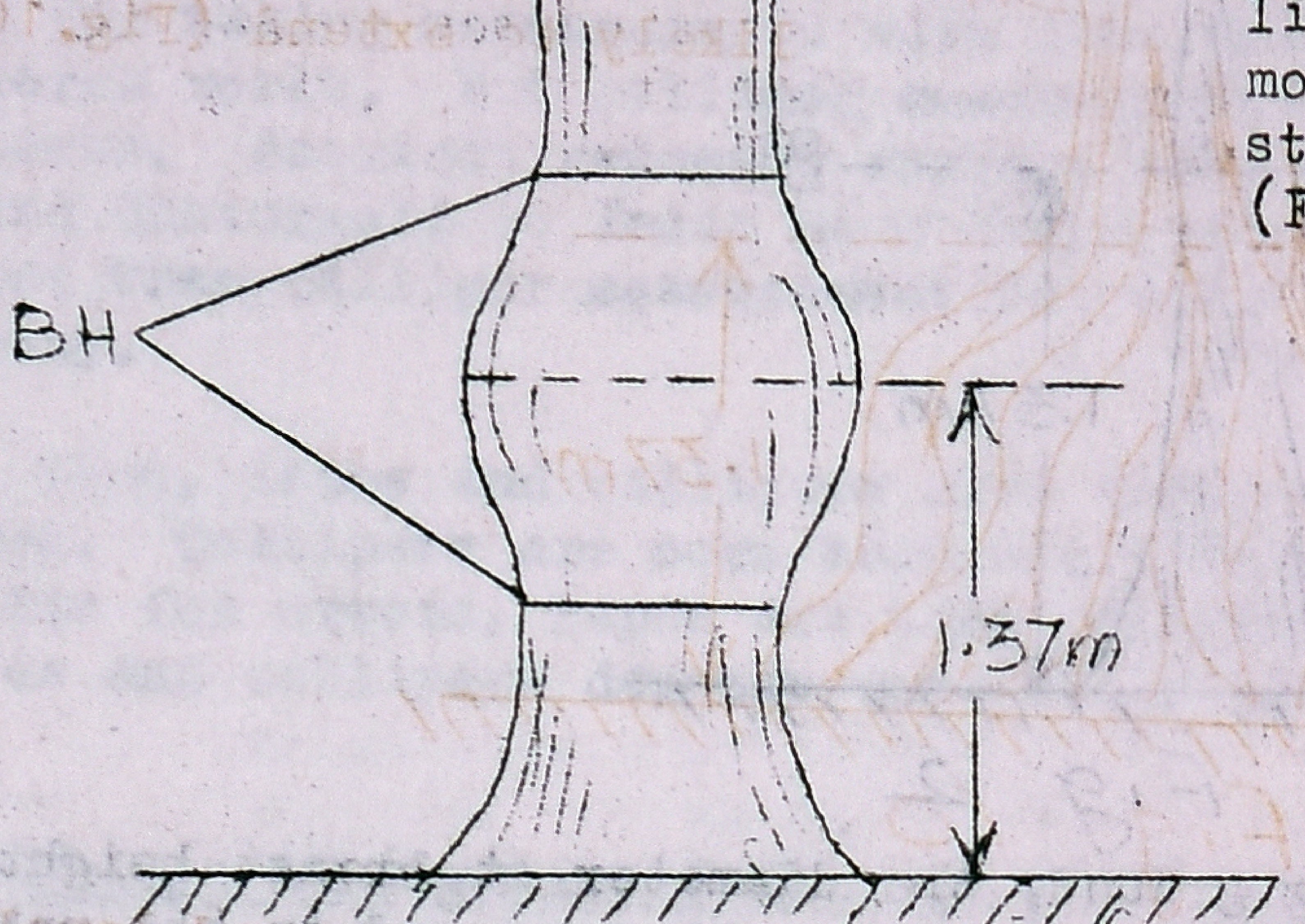


Fig 6

vi. Climbers, moss, lichen, loose bark, etc. should be removed by hand or with a rough stick before measurement.

vii. In case of forked trees; a) when the tree is forked above the breast height it is counted as one tree (Fig.7).

b) If the tree is forked below the breast height each fork is treated as a separate tree (Fig.8).

c) If forking renders the breast height point abnormal, the foregoing rule should be adopted and the tree should be counted as one or two depending upon the place of measurement (Fig.9).

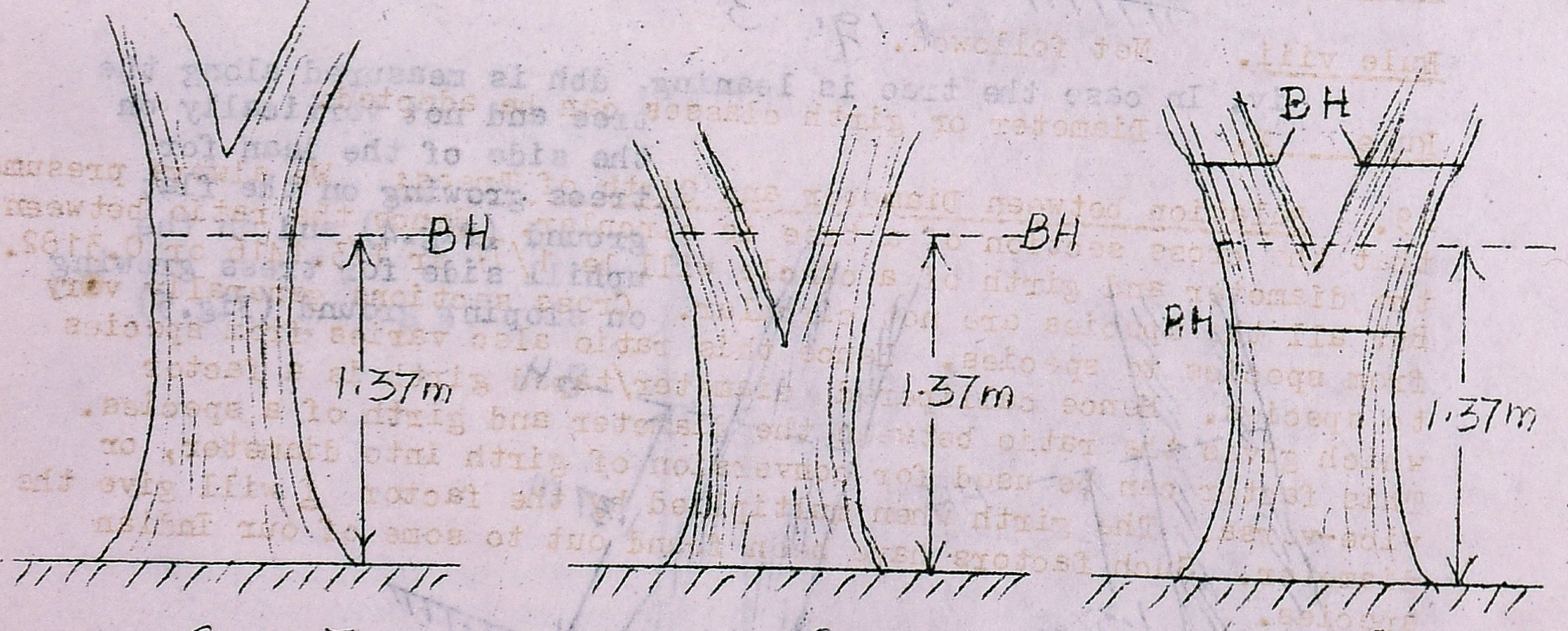


Fig 7 Fig 8 Fig 9

viii. If buttress formation is characteristic of the species and is likely to extend upwards with the development of the tree, the breast height should be taken at the lowest point, above which the abnormal formation is not likely to extend (Fig.10).

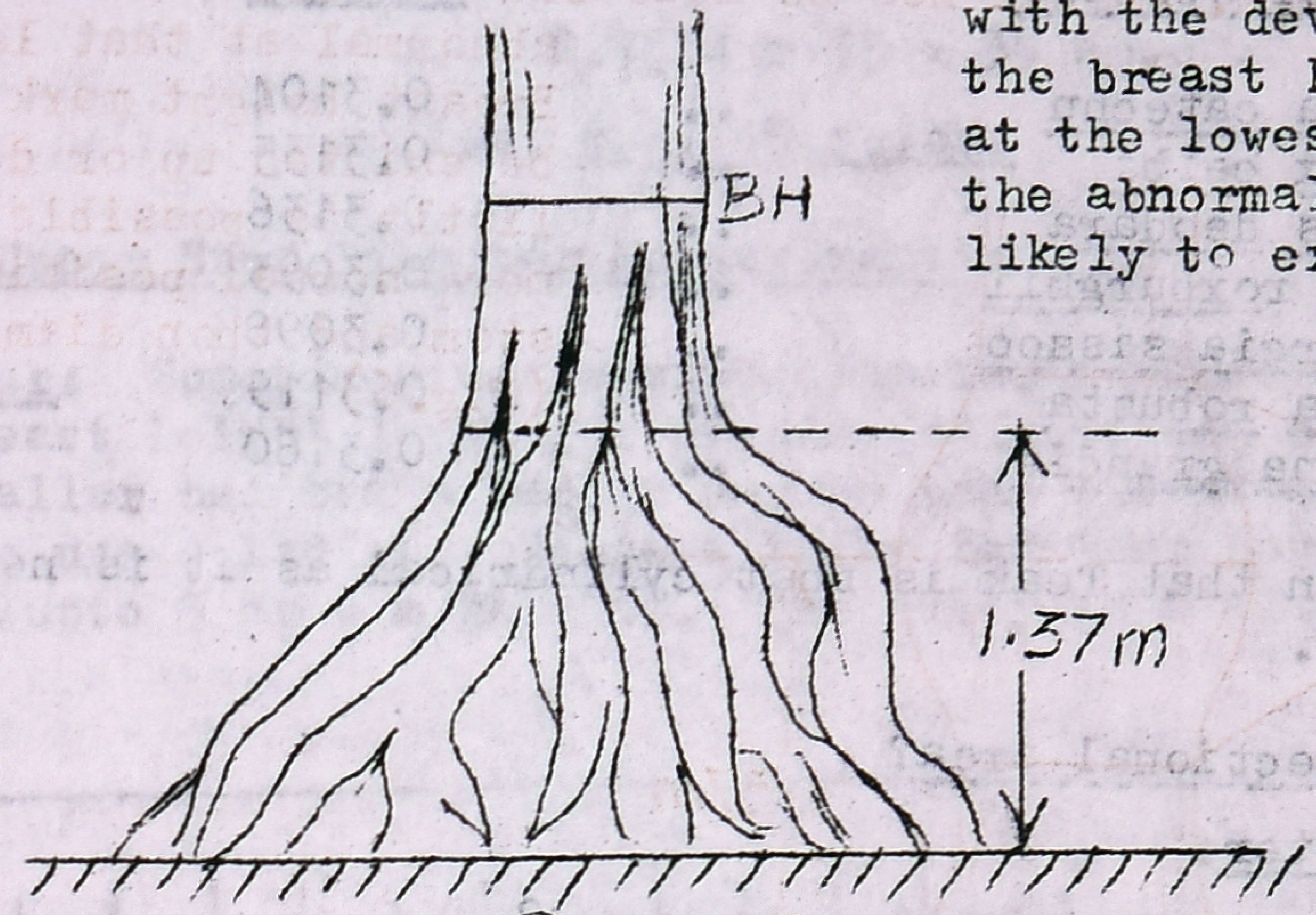


Fig. 10

ix. The height of the cross mark above the ground level should always be recorded for each tree measured.

x. Diameters should be measured in centimetres and to the nearest multiple of 2mm whereas the girth should be recorded to the nearest centimetre.

Above rules should be strictly followed when measurements are recorded for purposes of research and statistics. If the measurements are made for routine forest works, above rules may be modified as follows:

Rule i. Diameters and girths are measured at breast height but measuring stick is not necessary.

Rule ii. Not necessary.

Rule viii. Not followed.

Rule x. Diameter or girth classes can be adopted.

29. Relation between Diameter and Girth of Trees: We always presume that the cross section of a tree is circular. Hence the ratio between the diameter and girth of a circle will be $1/\pi$ or 1/3.1416 or 0.3182. But all the species are not circular. Cross sections generally vary from species to species. Hence this ratio also varies from species to species. Hence callipered diameter/taped girth is a factor which gives the ratio between the diameter and girth of a species. This factor can be used for conversion of girth into diameter, or vice-versa. The girth when multiplied by the factor f will give the diameter. Such factors have been found out to some of our Indian species.

Name of species		f = d/g
Acacia catechu	..	0.3104
Bombax ceiba	..	0.3135
Cedrus deodara	..	0.3136
Pinus roxburghii	..	0.3093
Dalbergia sissoo	..	0.3098
Shorea robusta	..	0.3119
Tectona grandis	..	0.3160

It may be seen that Teak is most cylindrical as it is nearer to the value of 0.3182.

30. How to find sectional area?

i. From diameter:

We know that area of circle is πr^2

But r = d/2 where

r = radius, d = diameter. Substituting d/2 for r,

Area or $s = \pi r^2$ or $\pi \times d/2 \times d/2$ i.e. $\frac{\pi d^2}{4}$

i.e., $\frac{\pi}{4} \times d^2$ i.e. $\frac{3.1416}{4} \times d^2$ i.e. $0.7854 d^2$

Hence sectional area = $0.7854 d^2$

ii. From Girth:

We know that girth or 'g' = $2\pi r$ or πd.

$S = \pi r^2$ or $\frac{\pi d^2}{4}$ But $g = \pi d$.

Hence $d = g/\pi$

Hence $S = \frac{\pi \times g/\pi \times g/\pi}{4}$

i.e. $\frac{\pi \times g}{\pi} \times \frac{g}{\pi} \times \frac{1}{4}$

i.e. $\frac{g^2}{4\pi}$ i.e. $\frac{1}{4\pi} \times g^2$ i.e. $\frac{1}{4 \times 3.1416} \times g^2$

i.e. $0.07958 g^2$

Hence sectional area = $0.07958 g^2$

Example: Calculate the Basal area.

(a) Tree with g.b.h. of 110 cm
(b) Tree with d.b.h. of 35cm

(a) $S = 0.07958 g^2$

$= 0.07958 \times 110 \times 110$ Sq.cm.

= i.e. 962.918 Sq.cm.

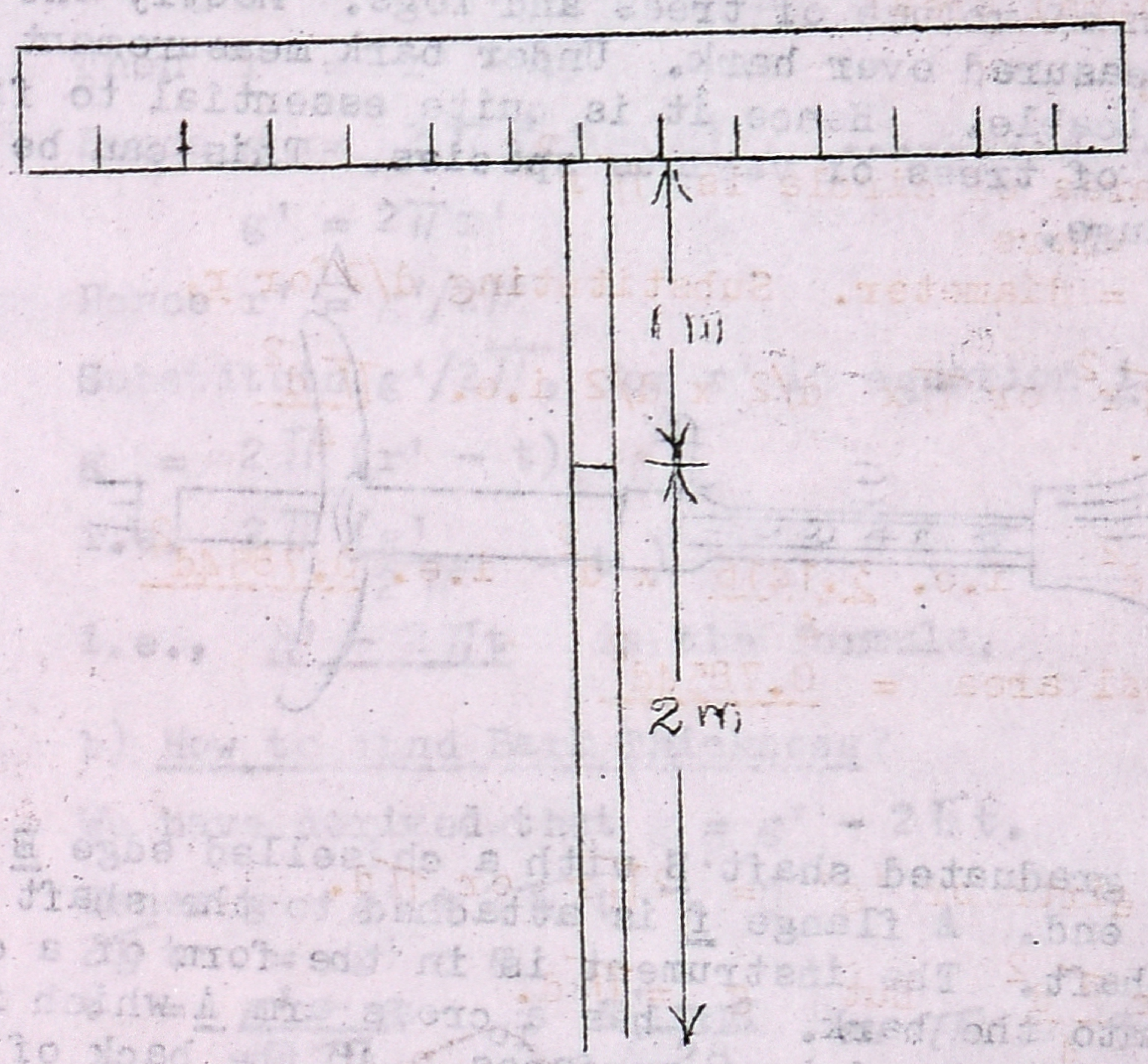
(b) $S = 0.7854d^2$

i.e. $0.7854 \times 35 \times 35$ sq.cm.

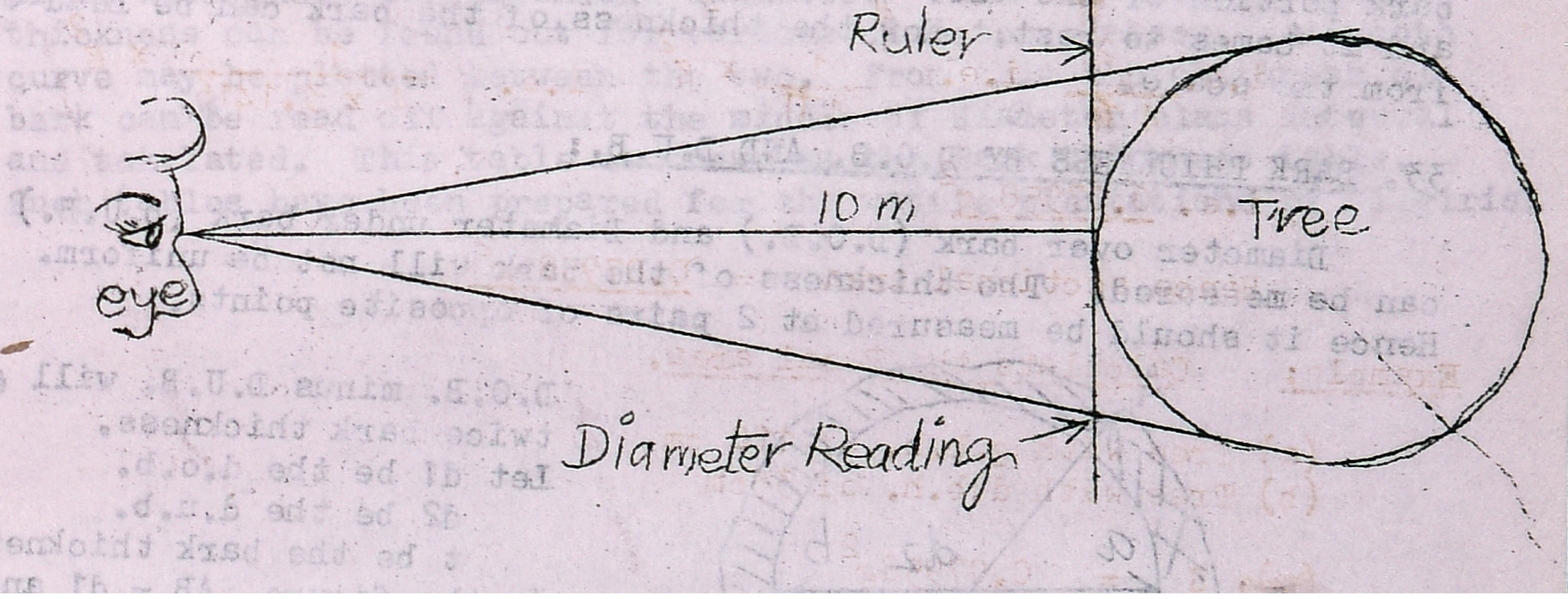
i.e. <u>962.115 sq.cm.</u>

31. **Upper Stem Diameter Measurements:**

i. Ruler: Sometimes we require diameter measurements of trees above the breast height level for precise calculation of basal area and volume For smaller heights a ladder may be used but it is not always practicable to use a ladder. Hence a ruler has been devised to measure diameters upto 5 or 6 m heights. The ruler is a simple board of 150cmx10cm x1cm with one meter rod attached to the middle. A 2m long detachable handle can be fitted with this. The board is white in colour and graduations are marked with black paint. The diameter marks are not exact linear measurement. They are slightly corrected to avoid parallax errors. The ruler is usually graduated so as to read the diameters from a horizontal distance of 10m.



The observer should stand at a horizontal distance of 10m. from the side of the tree. A helper will place the ruler against the tree at the chosen height of the tree. It should be kept perpendicular to the line of sight. The left edge of the ruler should be in line with the left edge of the stem in relation to the observer.

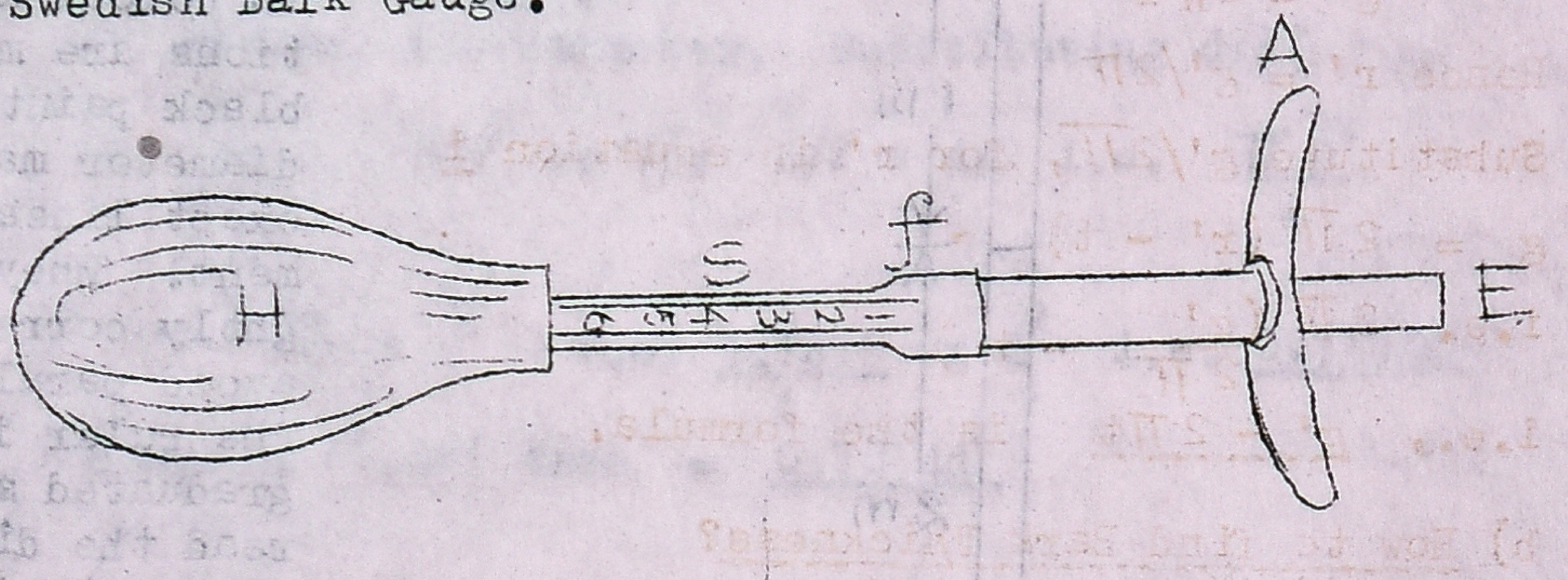


The diameter can then be read on the right hand part of the ruler as shown in the above figure.

ii. Dendrometers: For diameter measurements at still greater heights, dendrometers can be used. They are optical instruments with which diameter measurements can be taken at any point up the stem. The principle of similar triangles are adopted. These instruments have not proved to be of much practical value and they do not have any high degree of accuracy.

32. Measurement of Bark Thickness:

By Bark Gauge: The thickness of bark varies from species to species; from tree to tree with difference in age; also in the same tree from base to the top portion of the tree. This bark thickness affects the calculation of volume of trees and logs. Mostly the girth or diameter is measured over bark. Under bark measurement for each tree is not practicable. Hence it is quite essential to find out the bark thickness of trees of various species. This can be found out by Swedish Bark Gauge.

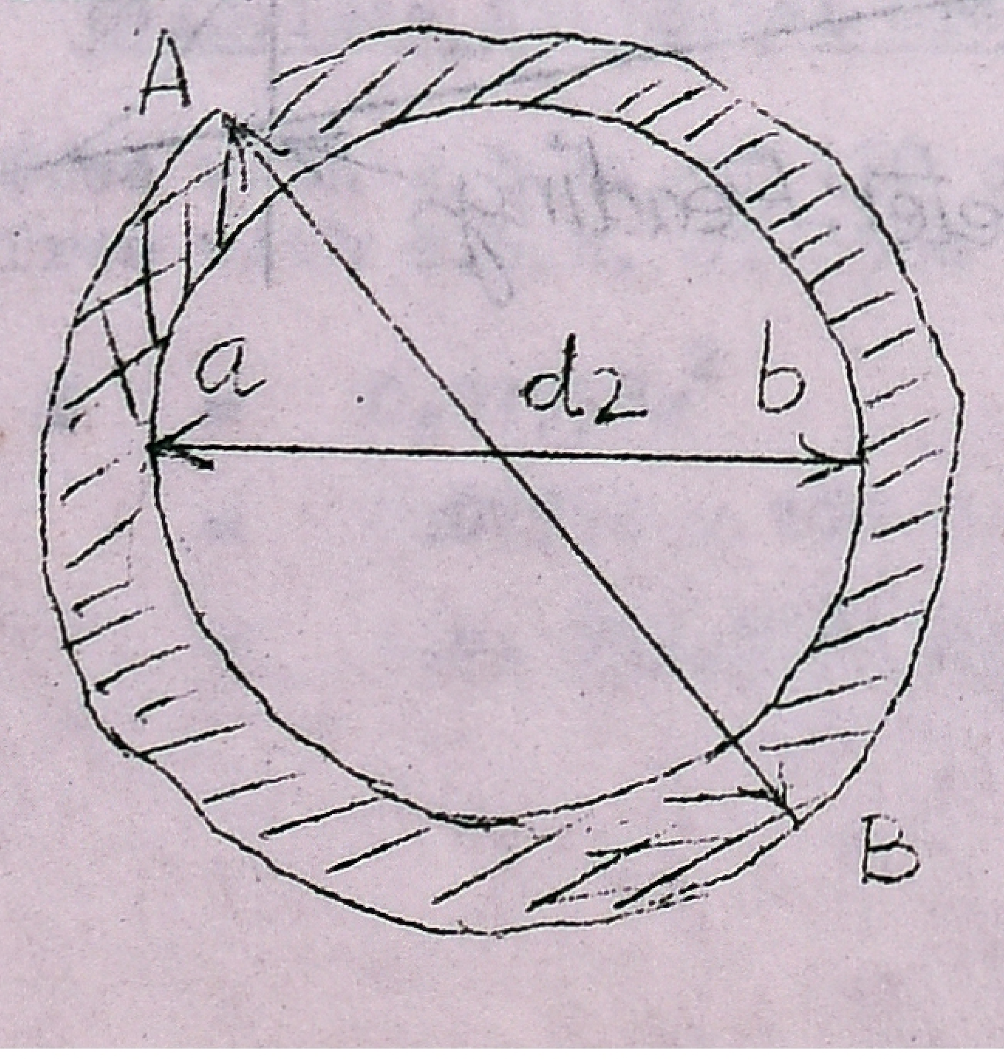


It consists of a graduated shaft S with a chiselled edge E and handle H in the other end. A flange f is attached to the shaft which can slide along the shaft. The instrument is in the form of a chisel which can be pushed into the bark. It has a cross arm A which is curved to fit in with the curved tree surfaces. At the back of this curved arm is fitted a tube which moves on chisel which is graduated in cm and mm. When the cross arm is at the extreme edge of the chisel the tube touches the zero point.

The gauge is just applied to the stem surface of the tree at right angle to its axis and the gauge is worked to penetrate the bark portion of the tree completely. Now the tube is pushed back and it comes to rest. Now the thickness of the bark can be read off from the scale.

33. BARK THICKNESS BY D.O.B. AND D.U.B.:

Diameter over bark (D.O.B.) and Diameter under bark (D.U.B.) can be measured. The thickness of the bark will not be uniform. Hence it should be measured at 2 pairs of opposite points.



D.O.B. minus D.U.B. will give twice bark thickness.
Let d1 be the d.o.b.
d2 be the d.u.b.
t be the bark thickness.
In the figure, AB = d1 and ab is d2.

Then a) $t = \frac{d1 - d2}{2}$ and hence,

b) $2t = d1 - d2$

c) $d1 = d2 + 2t$

d) $d2 = d1 - 2t$

Diameter under bark can be measured by making incisions of the bark at the points of measurements in the case of standing trees. In the case of felled trees, bark thickness may be directly measured with a foot rule or derived as explained above.

34. BARK THICKNESS BY G.O.B. AND G.U.B.:-

a) Relation between G.O.B. & G.U.B.: G.O.B. can be converted to G.U.B. by the formula $g = g' - 2\pi t$, where g = gub; g' = gob and t = bark thickness. Derivation of this formula is given below.

We know that $g = 2\pi r$.

Let r be radius; UB and r' be the radius O.B.

Then $r = r' - t$

Hence $g = 2\pi(r' - t)$ .... i.

$g' = 2\pi r'$

Hence $r' = g'/2\pi$

Substitute $g'/2\pi$, for r' in equation i

$g = 2\pi(r' - t)$

i.e. $2\pi\left(\frac{g'}{2\pi} - t\right)$

i.e., $g' - 2\pi t$ is the formula.

b) How to find Bark Thickness?

We have derived that $g = g' - 2\pi t$.

Hence $g - g' + 2\pi t = 0$

$2\pi t = g' - g$

$t = \frac{g' - g}{2\pi}$ or $\frac{g' - g}{6.28}$ as $\pi = 3.14$.

35. BARK THICKNESS TABLE:

Suppose we want to find out the bark thickness of a particular species we can prepare a bark thickness table. Bark thickness can be found out for large number of trees of the particular species along with their corresponding diameter. Then the average bark thickness can be found out for various diameter classes. A smooth curve may be plotted between the two. From this the thickness of bark can be read off against the middle of diameter class interval and tabulated. This table is known as the Bark thickness table. Such tables have been prepared for the wattle plantations of Nilgiris.

An example is given below as prepared by Lohani for Twisted Chir.

Dia. class cm	Bark thickness cm	Twice bark thickness cm
30.1 - 40.0	1.80	3.60
40.1 - 50.0	1.94	3.88
50.1 - 60.0	2.09	4.18
60.1 - 70.0	2.24	4.48
70.1 - 80.0	2.38	4.76

36. BARK PERCENT: For some species like wattle, bark is important. In some other species, volume or weight of wood is influenced by bark. In such cases it will be essential to have an idea of bark percent. The bark per cent can be found out by using the formula.

$$\text{Bark percent} = \frac{\text{g.o.b.} - \text{g.u.b.}}{\text{g.o.b.}} \times 100$$

Bark volume percent for the trees or logs can be found out by the following formula:

$$\text{Bark volume percentage} = \frac{\text{Volume with bark} - \text{Volume without bark} \times 100}{\text{Volume with bark}}$$

The bark volume percentage can also be found out by the following formula i.e.

$$\frac{\text{g.o.b.}^2 - \text{g.u.b.}^2}{\text{g.o.b.}^2} \times 100$$

$$\text{or } \frac{(\text{g.o.b.} + \text{g.u.b.})(\text{g.o.b.} - \text{g.u.b.})}{\text{g.o.b.}^2} \times 100$$

The above formula is based on the principle that for a log or tree of given length, volume is proportional to the square of its girth or diameter. Only Bark volume percent will give a correct idea of bark content in a tree or log. The Bark volume percentage can also be found by the following formula, if diameter alone is known, on the above presumption.

$$\text{i.e. } \frac{\text{dob}^2 - \text{dub}^2}{\text{dob}^2} \times 100$$

$$\text{or } \frac{(\text{dob} + \text{dub})(\text{dob} - \text{dub})}{\text{dob}^2} \times 100$$

37. Bark Percentage Table: Whether bark is important as a produce as in the case of wattle or bark percent has a direct bearing on the volume or weight of the wood, a bark percentage table can be prepared for such species. The table is prepared by measuring a large number of trees and calculating the percentage of bark and wood in each. These tables will give the percentage of wood and bark for different diameter classes, by following the data of volume against diameters of trees and drawing a smooth curve. From the curve, percentage of bark and wood against the middle of the diameter class interval can be read off and tabulated. An example of such table prepared by Lohani for twisted Chir is given below.

Diameter class in cm.	Bark percentage of total volume	Wood percentage of total volume
20.1 - 30.0	25.70	74.30
30.1 - 40.0	24.15	75.85
40.1 - 50.0	21.80	78.20
50.1 - 60.0	18.85	81.15
60.1 - 70.0	16.25	83.75
70.1 - 80.0	14.20	85.80
80.1 - 90.0	12.80	87.20

PROBLEMS

1. Find the Basal areas in sq. metres of trees having breast height girth of a) 88 cm b) 115cm c) 125 cm d) 140 cm e) 155 cm.

Example:

a) Sectional area = $0.07958\ g^2$
Here the girth is 88 cm.
Hence area = $0.07958 \times \frac{88}{100} \times \frac{88}{100}$ i.e. 0.0616 Sq.m.

b) Sectional area = $0.07958 \times \frac{115}{100} \times \frac{115}{100}$

i.e. 0.1052 sq.m.

Note: You can work out the remaining sums.

2. Find out the Basal area if the diameter at breast height is a) 21cm b) 25cm c) 30cm d) 40cm e) 45cm f) 50 cm.

a) Sectional area = $0.7854d^2$

i.e. $0.7854 \times \frac{21}{100} \times \frac{21}{100}$

i.e. 0.0346 sq. metres

b) Sectional area = $0.7854 \times \frac{25}{100} \times \frac{25}{100}$

i.e. 0.0491 sq. metres.

Note: Work out the remaining problems.

3. Find out a) Bark thickness b) Bark percentage and c) Bark colume percentage in the following cases:

i) G.O.B. is 140 cm G.U.B. 127 cm.
ii) G.O.B. is 152 cm G.U.B. 135 cm.
iii) G.O.B. is 120 cm G.U.B. 98 cm.
iv) G.O.B. is 162 cm G.U.B. 140 cm.

i) <u>Bark thickness</u>

$$t = \frac{g' - g}{6.28} \quad \text{where } t = \text{thickness}, \; g' = \text{g.o.b.} = 140 \text{ cm}, \; g = \text{g.u.b.} \; 127 \text{ cm}$$

Hence Bark thickness $= \frac{140 - 127}{6.28}$

i.e. $\frac{13}{6.28}$

i.e. 2.07 cm

ii) G.O.B. is 152 cm g.u.b. = 135 cm

$$t = \frac{g' - g}{6.28}$$

i.e. $\frac{152 - 135}{6.28}$

i.e. $\frac{17}{6.28}$

i.e. 2.707 cm

Note: Work out other problems similarly.

b) <u>Bark Percentage:</u>

i) Bark percent $= \frac{\text{g.o.b.} - \text{g.u.b.}}{\text{g.o.b.}} \times 100$

Here g.o.b. = 140cm and g.u.b. = 127 cm.

Hence bark percent $= \frac{140 - 127}{140} \times 100$

i.e. $\frac{13}{140} \times 100$

i.e. 9.28%

ii) Bark percent $= \frac{152 - 135}{152} \times 100$

i.e. $\frac{17}{152} \times 100$

i.e. 11.18%

Note: Work out other problems.

c) <u>Bark volume percentage:</u>

i) Bark volume percent $= \frac{\text{g.o.b}^2 - \text{g.u.b}^2}{\text{g.o.b}^2} \times 100$

Here g.o.b. = 140 cm and g.u.b. = 127 cm.

Bark volume percent $= \frac{(140 + 127)\,(140 - 127)}{140 \times 140} \times 100$

i.e. $\frac{2.67 \times 13}{140 \times 140} \times 100$

i.e. 17.709%

ii) Here g.o.b. = 152 cm and g.u.b. = 135 cm.
Applying the above formula bark volume % = $\frac{152^2 - 135^2}{152^2} \times 100$

i.e. $\frac{(152 + 135)(152 - 135)}{152 \times 152} \times 100$

i.e. $\frac{287 \times 17}{152 \times 152} \times 100$

i.e. 21.118%

Note: Work out the other problems similarly.

4. Find the girth under bark when i) g.o.b. = 88 cm and bark thickness is 2.8cm; ii) g.o.b. 120 cm and bark thickness is 3.8cm; iii) g.o.b. is 142 cm and bark thickness is 4.2 cm and iv) g.o.b. is 165 cm and bark thickness is 5.5 cm.

i) Given g.o.b. is 88 cm and bark thickness is 2.8 cm. We know the formula $g = g' - 2\pi t$. Where g = g.u.b.,
g' = g.o.b. and
t = Bark thickness.

Applying this formula,

g.u.b. = 88 - (2 x π x 2.8)
i.e. 88 - (2 x 3.1416 x 2.8)
i.e. 88 - 17.59
i.e. 70.41 cm. Answer

ii) g.o.b. is 120 cm; t = 3.8 cm
g.u.b. = 120 - (2 x 3.1416 x 3.8)
i.e. 120 - 23.88
i.e. 96.12 cm.

Note: Work out the remaining problems yourself.

5. Find a) bark thickness b) bark percentage and c) bark volume percent if i) d.o.b. is 58 cm and D.U.B. is 55 cm; ii) D.O.B. is 65 cm and D.U.B. is 60 cm; iii) D.O.B. is 75 cm and D.U.B. is 68 cm; iv) D.O.B. is 92 cm and D.U.B. is 87 cm.

a) Bark thickness

$t = \frac{d.o.b. - d.u.b.}{2}$

= Here D.O.B. is 58 cm and D.U.B. is 55 cm.

Hence Bark thickness is $\frac{58 - 55}{2}$

i.e. 1.5 cm.

b) Bark percent $= \frac{g.o.b. - g.u.b.}{g.o.b.} \times 100$

g.o.b. $= 58 \times \pi$ i.e. $3.1416 \times 58 = $ 188.2 cm.

g.u.b. $= 55 \times \pi$ i.e. $3.1416 \times 55 = $ 172.8 cm.

Bark % $= \frac{g.o.b. - g.u.b.}{g.o.b.} \times 100$

i.e. $\frac{182.2 - 172.8}{182.2} \times 100$

i.e. $\frac{94 \times 100}{182.2}$

i.e. 5.159%

We can adopt the formula $\frac{d.o.b. - d.u.b.}{d.o.b.} \times 100$

i.e. $\frac{58 - 55}{58} \times 100$

i.e. $\frac{3}{58} \times 100$

i.e. 5.17%

c) Bark volume percent:

Bark volume percent $= \frac{(g.o.b. + g.u.b.)(g.o.b. - g.u.b.)}{g.o.b. \times g.o.b.} \times 100$

i.e. $\frac{(182.2 + 172.8)(182.2 - 172.8)}{182.2 \times 182.2} \times 100$

i.e. $\frac{3.55 \times 9.4 \times 100}{182.2 \times 182.2}$

i.e. 10.09%

We can also use the formula

Bark volume percent $= \frac{(d.o.b. + d.u.b.)\ (d.o.b. - d.u.b.)}{\frac{2}{d.o.b.}} \times 100$

i.e. $\frac{(58 + 55)\ (58 - 55)}{58 \times 58} \times 100$

i.e. $\frac{113 \times 3}{58 \times 58} \times 100$

i.e. 10.07%

ii) Bark thickness

$t = \frac{d1 - d2}{2}$

i.e. $\frac{d.o.b. - d.u.b.}{2}$

i.e. $\frac{65 - 60}{2}$ i.e. $\frac{5}{2}$ i.e. 2.5 cm.

b) Bark percentage:

D.O.B. is 65 cm D.U.B. = 60 cm.
Hence G.O.B. = 65 x 3.1416 = 204.2 cm.
G.U.B. = 60 x 3.1416 = 188.5 cm.

$$\text{Bark percent} = \frac{\text{g.o.b.} - \text{g.u.b.}}{\text{g.o.b.}} \times 100$$

$$\text{i.e.} \quad \frac{204.2 - 188.5}{204.2} \times 100$$

$$\text{i.e.} \quad \frac{15.7}{204.2} \times 100$$

i.e. 7.69%

If we adopt the formula Bark % is $\frac{\text{d.o.b.} - \text{d.u.b}}{\text{d.o.b}} \times 100$

then it will be $\frac{65 - 60}{65} \times 100 = \frac{5}{65} \times 100$ i.e. 7.69%

Hence both the formula can be used.

c) Bark volume percentage:

$$\text{Bark volume percentage:} \quad \frac{(\text{g.o.b.} + \text{g.u.b.})\ (\text{g.o.b.} - \text{g.u.b.})}{\text{g.o.b.} \times \text{g.o.b.}} \times 100$$

$$\text{i.e.} \quad \frac{(204.2 + 188.5)\ (204.2 - 188.5)}{204.2 \times 204.2} \times 100$$

$$\text{i.e.} \quad \frac{392.7 \times 15.7 \times 100}{204.2 \times 204.2}$$

i.e. 14.78%

If we adopt the formula

$$\text{Bark volume percent} = \frac{(\text{d.o.b.} + \text{d.u.b.})\ (\text{d.o.b.} - \text{d.u.b.})}{\text{d.o.b.} \times \text{d.o.b.}} \times 100$$

$$\text{i.e.} \quad \frac{(65 + 60)\ (65 - 60)}{65 \times 65} \times 100$$

$$\text{i.e.} \quad \frac{125 \times 5 \times 100}{65 \times 65}$$

i.e. 14.79%

Hence both the formula can be used.

Note: Work out the remaining problems yourself.

6. Find the diameter over bark if i) d.u.b. is 50cm and bark thickness is 2 cm ii) d.u.b. is 60 cm and bark thickness is 3 cm; iii) d.u.b. is 75 cm and bark thickness is 4 cm; iv) d.u.b. is 85cm and bark thickness is 5 cm.

$$\text{i) Bark thickness} \quad t = \frac{\text{d.o.b.} - \text{d.u.b.}}{2}$$

Hence 2t = d.o.b. - d.u.b.
Hence d.o.b= d2 + 2t.
Here d.u.b. is 50cm and t = 2 cm.
D.O.B. = 50 + (2 x 2)
i.e. 50 + 4
i.e. 54 cm.

ii) Similarly d.o.b. = d.u.b. + 2 t i.e. 60 + (2 x 3) i.e. <u>66 cm.</u>

<u>Note</u>: Work out the remaining problems yourself.

7. Find the diameter under bark if i) d.o.b. is 70cm and bark thickness is 4 cm; ii) d.o.b. is 95 cm and bark thickness is 5 cm; iii) d.o.b. is 45 cm. and bark thickness is 3cm; iv) d.o.b. is 38 cm. and bark thickness is 2 cm.

i) We know that $t = \frac{d.o.b. - d.u.b.}{2}$

i.e. 2t = d.o.b. - d.u.b.

Hence d.u.b. = d.o.b. - 2 t. Here the d.o.b. is 70 cm and t is 4 cm.
Hence d.u.b. = 70 - (2 x 4)
i.e. 70 - 8
i.e. <u>62 cm.</u>

ii) Similarly d.o.b. = d.u.b. - 2 t
Hence d.o.b. is 75 cm and t is 5 cm.
Hence D.U.B. = 95 - (2 x 5)
i.e. 95 - 10
i.e. <u>85 cm.</u>

<u>Note</u>: Work out the remaining sums yourself.

<u>Prepare answers for the following questions</u>:-

1. A tree's diameter is measured with a calliper and diameter tape. Will the readings be the same? If not in what way they differ and why?

2. Do you agree that accurate measurements can be taken with callipers? If not why? What will be errors?

3. Compare the instruments calliper and tape for measuring the diameter?

4. What are the standard rules that should be observed while taking measurements at Breast height?

5. What are the advantages and disadvantages of (1) callipers (2) Tape?

6. What is Breast height?
Why are the measurements of diameter and girths of standing trees generally taken at Breast height?

7. What are the precautions that should be taken while measuring diameters and girths with Tape and calliper?

CHAPTER III

MEASUREMENT OF HEIGHTS OF TREES

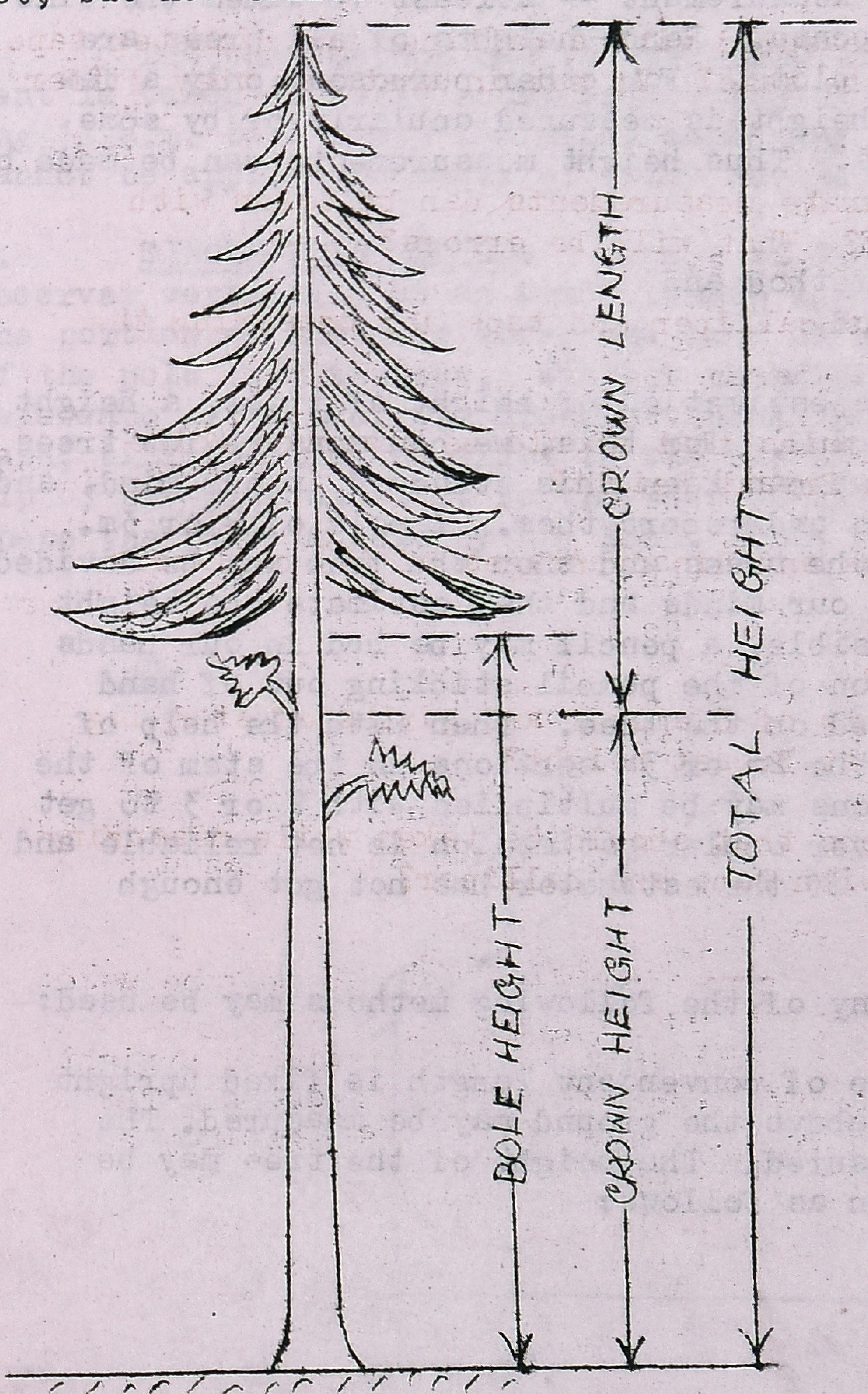
1. Objects of height measurement: Next to diameter and girth measurements, height is the important measurement. Height measurements are necessary

- i) to find out the volume of trees
- ii) to prepare volume table, form factor tables, yield tables, etc.
- iii) to find out the productive capacity of a site i.e. site quality by top height
- iv) to find out rate of growth of trees or increment in height growth.

2. Definitions: The various classes of heights are defined below:

a) Total height of a standing tree is the straight line distance from the tip of the leading shoot (or from the highest point of the crown where there is no leader) to the ground level, usually measured on slopes from the uphill side of the trees.

Total height of a felled tree should be measured in a straight line, without giving any allowance for the curvature in the stem. The stump height should be included. It should be measured nearest to a foot; but now correct to a decimetre under metric system.



b) Bole height: It is the distance from the ground level and crown point. The crown point is the position of the first crown forming living or dead branch. Bole height expresses the height or length of the clear main stem of a tree.

c) Commercial Bole height: It is the height of bole that is usually fit for utilisation as timber.

d) Height of standard timber bole: It is the height of the bole from the ground level upto the point where average diameter over bark is 20cm.

e) Stump height: It is the height of the top of the stump above ground. It gives the height of the tree stem which is left attached to the ground after felling.

f) Crown length: It is the vertical measurement of the crown of a tree from the tip to the point half way between the lowest green branches forming the green crown all around and the lowest green branch on the bole.

g) Crown height: It is the height of the crown as measured vertically from the ground level to the point half way between the lowest green branch and the green branches forming green crown all around.

3. METHODS OF MEASUREMENTS OF HEIGHT:

3.1 Theory of measurement: It must be realised that no tree is truly vertical. Most of the trees lean to one side or the other. But we always assume that the trees are mostly vertical. More the trees deviate from vertical position, more will be the errors. But this error is not going to matter much as the majority of trees are nearly vertical. But leaning trees can be measured by instruments if the angle of the lean is able to be measured. The heights of trees can be measured either without instruments or with the instruments.

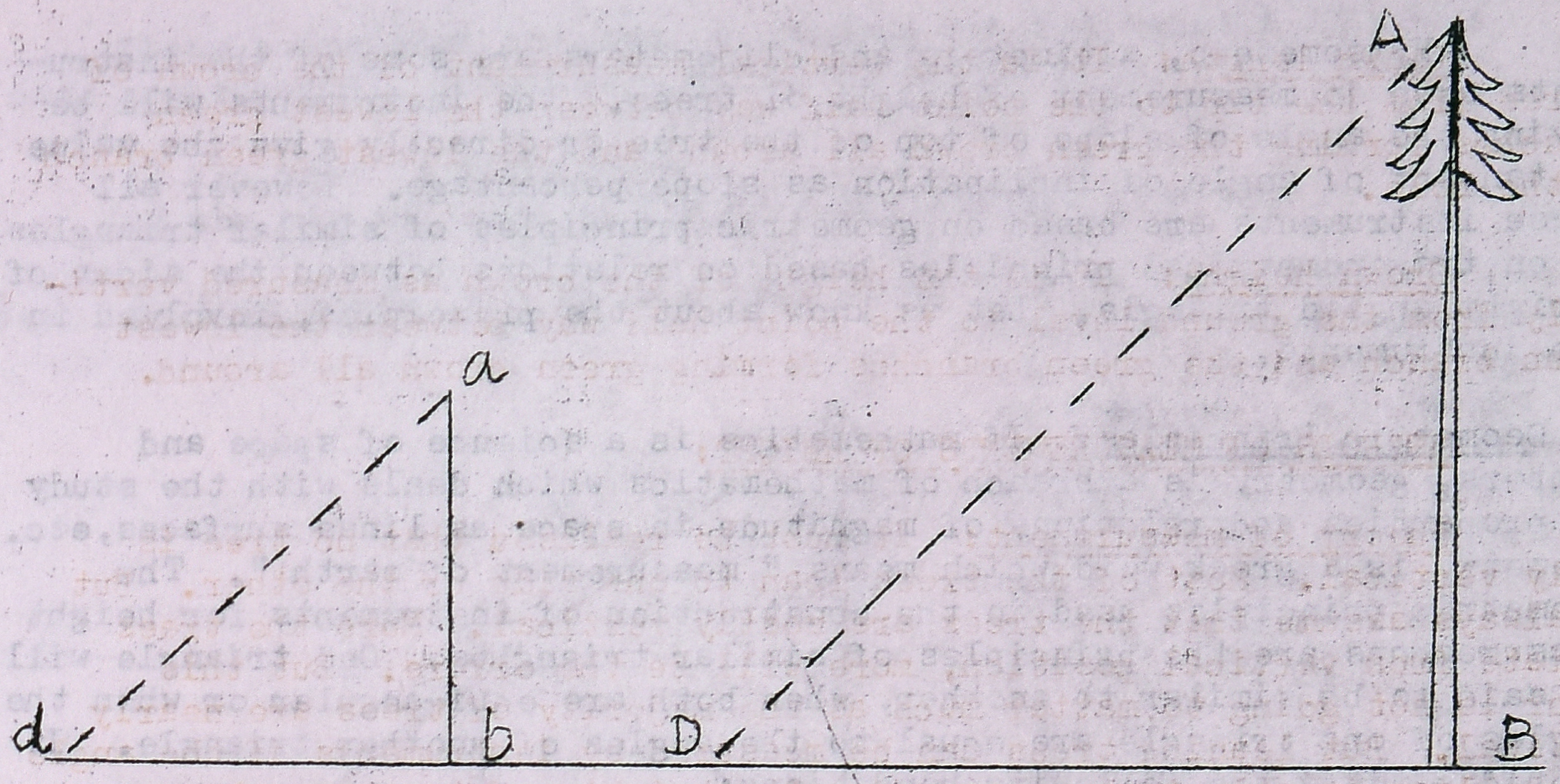
3.2 Height can be directly measured in the case of small trees with a pole or rod. Height measurement of very tall trees have to be done only by using instruments. Height measurement is a time consuming process, compared to diameter measurement -- atleast 10 times the time required for diameter measurements. Hence heights of all trees are measured only in small sample plots. For other purposes, only a few sample trees are measured or height is measured ocularly or by some other non-instrumental methods. Thus height measurements can be made by

i) ocular method
ii) non-instrumental method and
iii) instrumental method.

4. OCULAR METHOD: Before estimation of height of trees, a height scale has to be fixed in our mind. For this, we can measure few trees with the instruments so that we can keep this standard in our mind, and then judge the height of trees and record them. A pole of 2 or 3m. length can be placed against the trees and then the tree may be divided into 2m or 3m sections within our minds and then estimate the height of trees. If this is not possible, a pencil may be had in our hands in such a manner that a portion of the pencil sticking out of hand covers the 2m or 3m pole placed on the tree. Then with the help of pencil we can easily imagine the 2m or 3m sections in the stem of the tree, and the number of sections may be multiplied with 2 or 3 to get the height of the tree. However ocular estimation is not reliable and there will be serious errors if the estimator has not got enough experience.

NON-INSTRUMENTAL METHODS: Any of the following methods may be used:

5. Shadow method: A pole of convenient length is fixed upright in the ground and its height above the ground may be measured. The shadow of the pole may be measured. The height of the tree may be found out by simple proportion as follows:

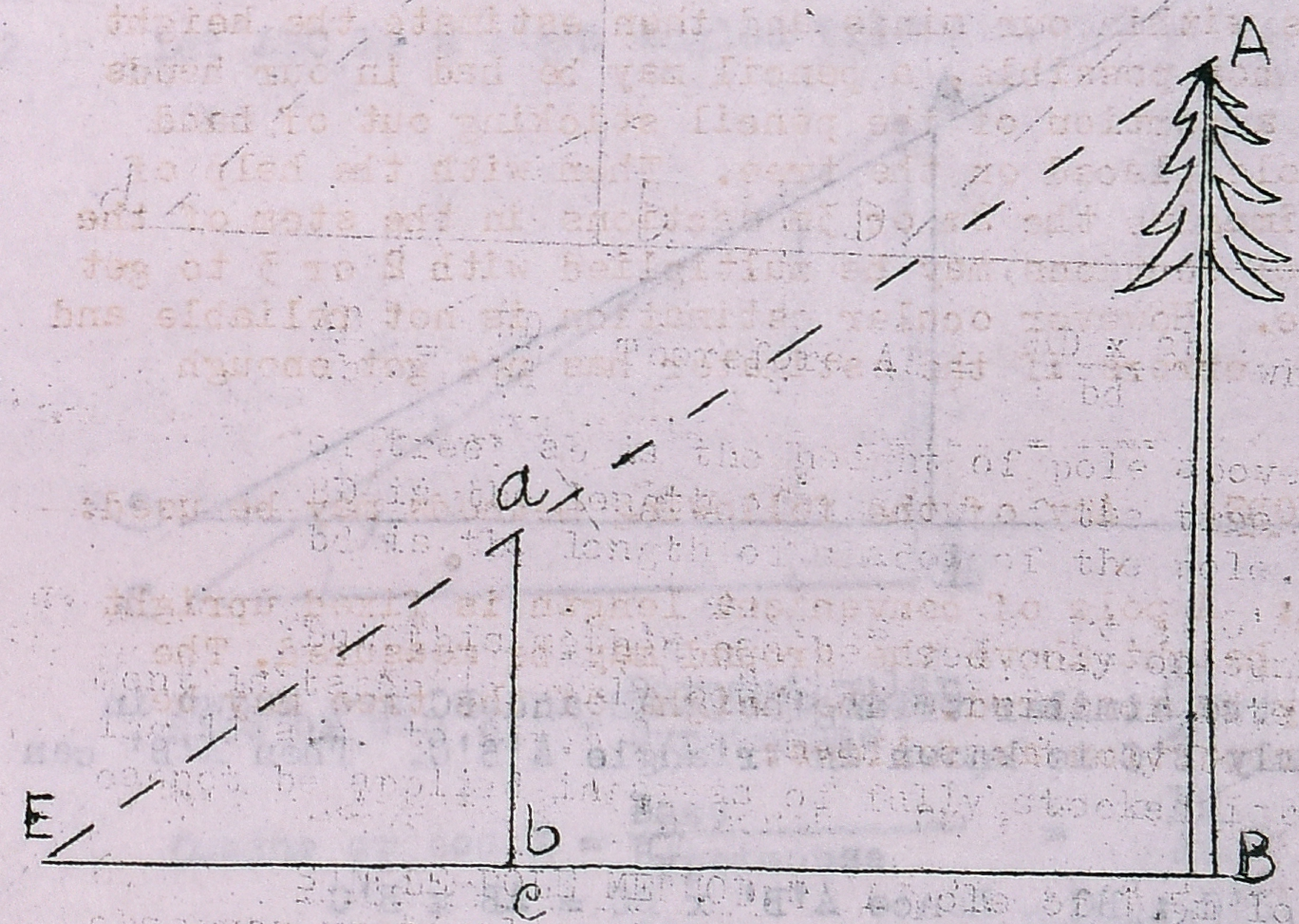


$$\frac{AB}{ab} = \frac{BD}{bd} \quad \text{Therefore } AB = \frac{BD \times ab}{bd}$$ where AB is the height of tree; ab is the height of pole above ground level; BD is the length of shadow of the tree and bd is the length of shadow of the pole.

But this method can be used only on sunny days. If the measurement is taken in early hours of morning or late hours of evening (avoiding 11 a.m. to 2 p.m.) the measurement may be accurate. This method cannot be applied in areas of fully stocked forest areas.

6. SINGLE-POLE METHOD: A pole of 1.5m long will be held by the observer vertically at an arm's length in one hand in such a way that the portion of the pole above the hand is equal in length to the distance of the pole from the eye. Without changing the position of hand with reference to the eye, the observer should move slowly forward and backward, till the line of sight to the tip of the tree passes through the tip of the pole and that to the base of the tree through the point where the pole is held by the hand. This means that the portion of the pole above the hand covers the tree completely. The height of the tree is then equal to the distance of the observer's eye from the base of the tree as explained below. Let AB be the tree and a pole of about 1.5 m. long held at b vertically so that the distance from the observer's eye to b is equal to ab, Then $\frac{AB}{ab} = \frac{EB}{Eb}$

Therefore $AB = \frac{EB \times ab}{Eb}$



since ab = Eb, AB = EB.

7. INSTRUMENTAL METHODS:

Hypsometers, altimeters and clinometers are some of the instruments used in measurement of height of trees. The instruments will be giving the angle of slope of top of the tree or directly give the value of tangent of angle of inclination as slope percentage. However all these instruments are based on geometric principles of similar triangles or on trigonometrical principles based on relations between the sides of a right angled triangle. Let us know about the principles, involved in the instruments.

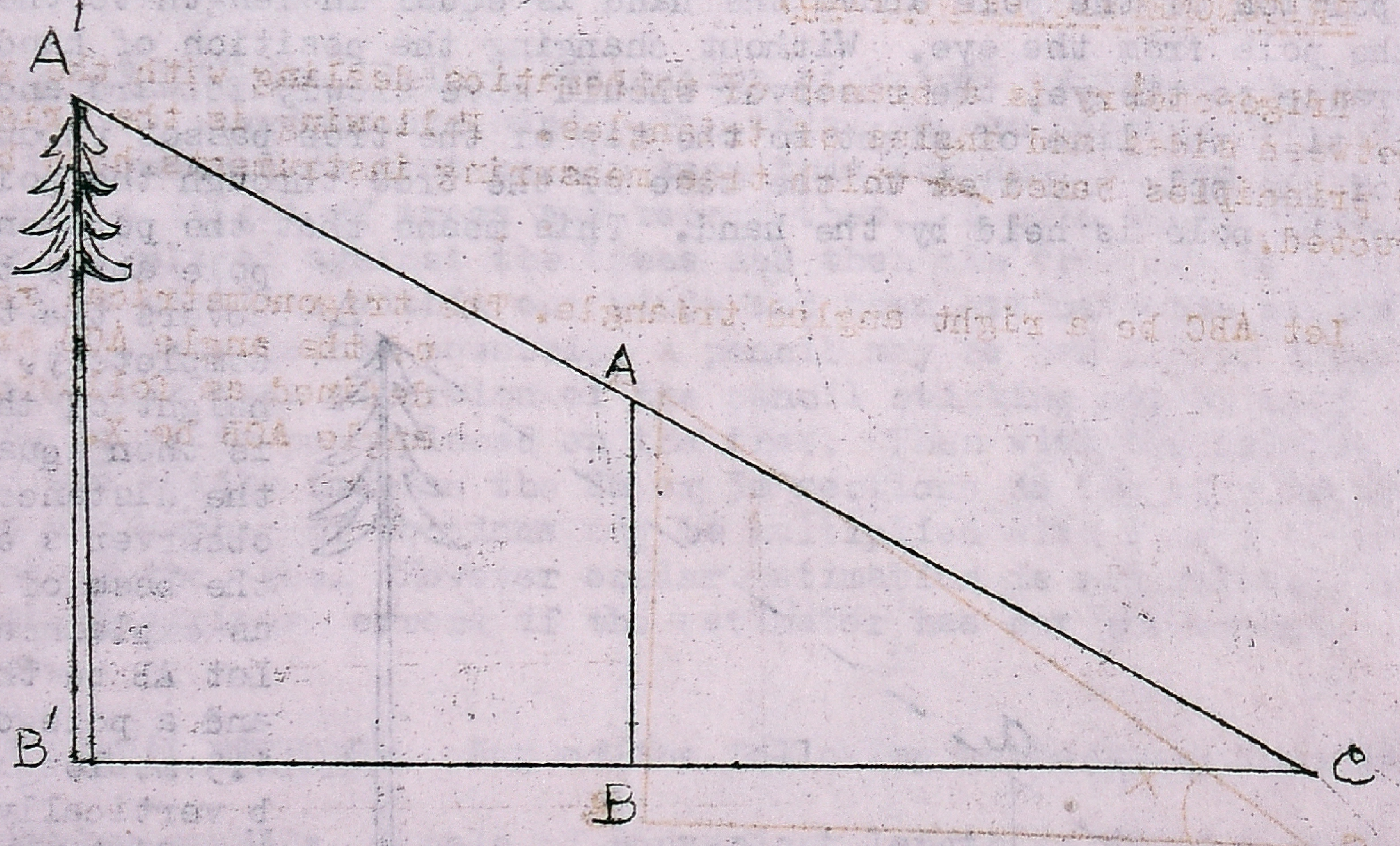
8. Geometric Principles: If mathematics is a science of space and numbers, geometry is a branch of mathematics which deals with the study of properties and relations of magnitude in space as lines surfaces, etc. Geometry is a greek word which means " measurement of earth ". The geometric principles used in the construction of instruments for height measurements are the principles of similar triangles. One triangle will be said to be similar to another, when both are equi-angular or when the angles of one triangle are equal to the angles of another triangle. It should satisfy the following conditions:

i) Each angle of a triangle is equal to its corresponding angle of the other triangle.

ii) Each side of a triangle is proportional to the corresponding side of the other triangle and

iii) One angle of a triangle is equal to one angle of the other and the corresponding sides which subtend the equal angles are proportional.

Hence they are copies of one another on the same scale. The sides may not be equal but the corresponding sides are proportional.



Let ABC and A'B'C be two similar triangles. AB and BC are known in triangle ABC. But only B'C is known in triangle A'B'C. Then A'B' can be found as follows:

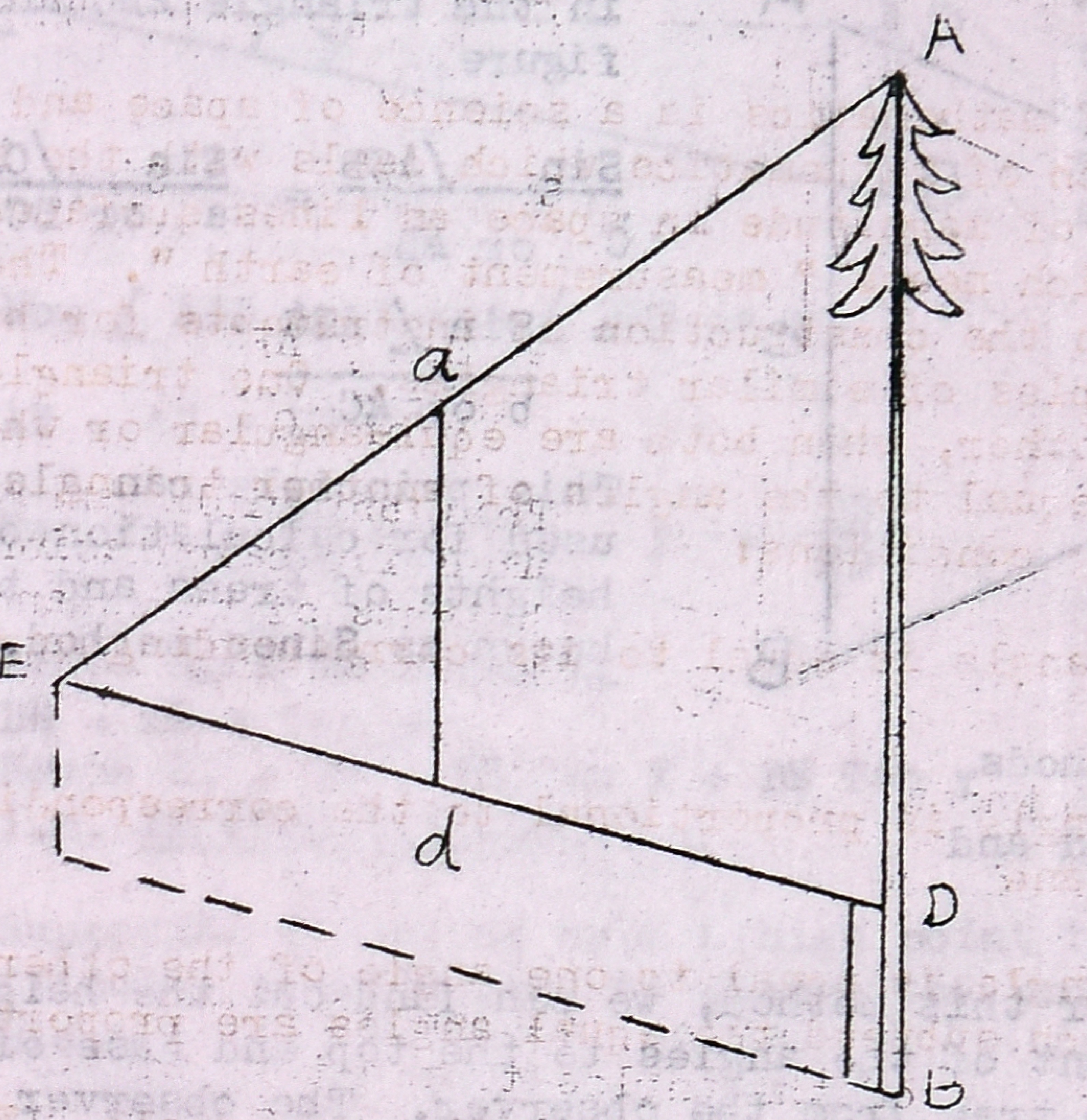
$A'B' : AB :: B'C : BC$ Hence $A'B' \times BC = AB \times B'C$

Therefore $A'B' = \dfrac{AB \times B'C}{BC}$

These principles are used in finding out the heights of trees by some instruments. For this purpose, we assume that

i) the tree is vertical and
ii) the tip and base of the tree are visible at a time.

ii) Another case: Let AB be a tree whose base is not visible to the observer from E. BD is the staff of height, equal to observer's eye-height as placed against the tree. Let ad be a plumb line of known length, suspended at known distance Ed. Then in the similar triangles ADE and adE, $\frac{AD}{ED} = \frac{ad}{Ed}$.



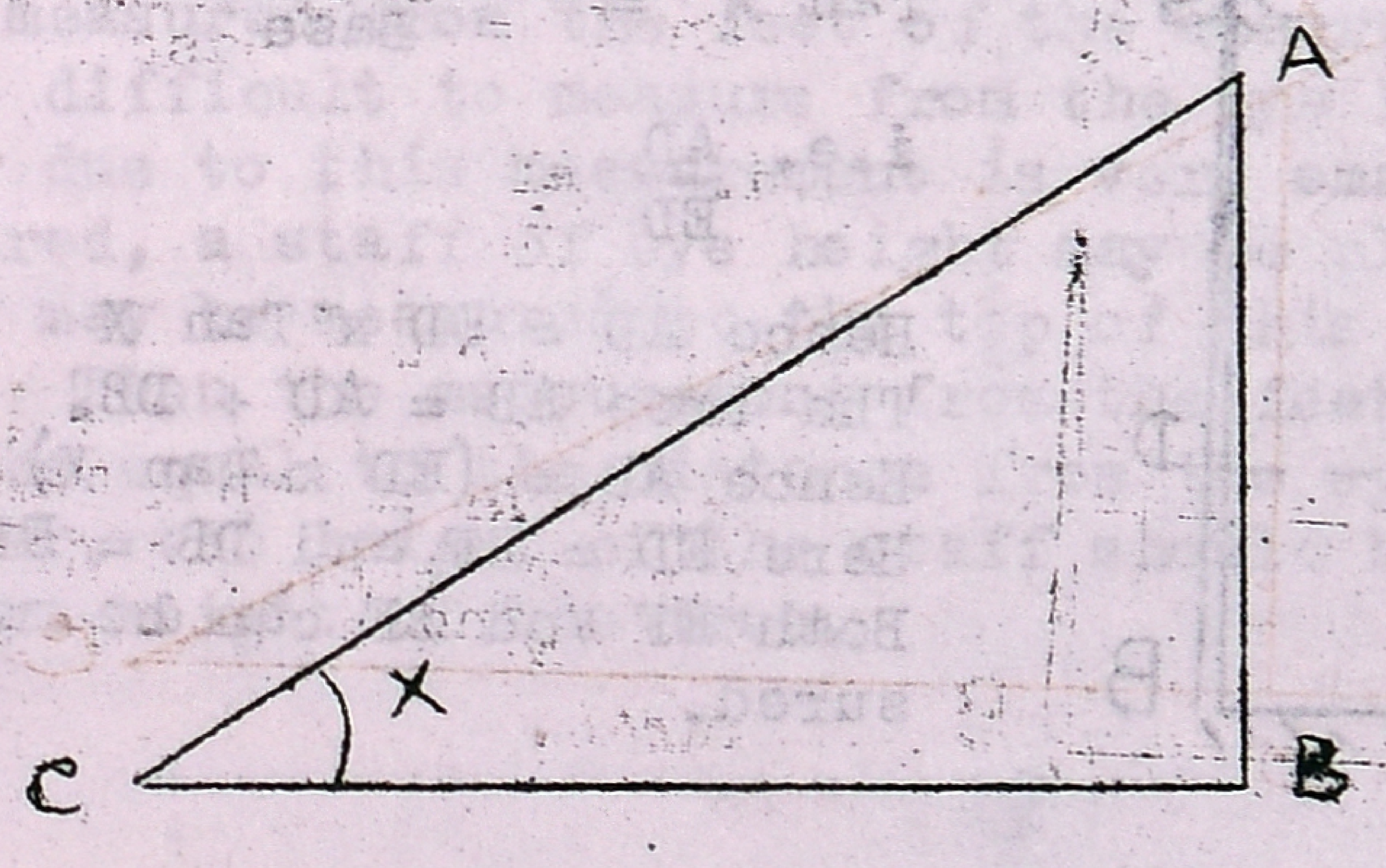
Therefore AD x Ed = EDxad
Hence AD = $\frac{ED \times ad}{Ed}$.

Here ad and Ed are known. ED can be measured on ground from observer's feet to the base of the tree. Hence AD can be found out. But the tree AB = AD + DB. DB's height can be measured. Hence when AB and DB are added we get the height of the tree.

9. TRIGONOMETRIC PRINCIPLES:

9.1 Trigonometry is a branch of mathematics dealing with the relation between sides and angles of triangles. Following is the trigonometric principles based ~~on~~ which tree measuring instruments have been constructed.

9.2 Let ABC be a right angled triangle. The trigonometrical ratios of the angle ACB are defined as follows. Let angle ACB be X.



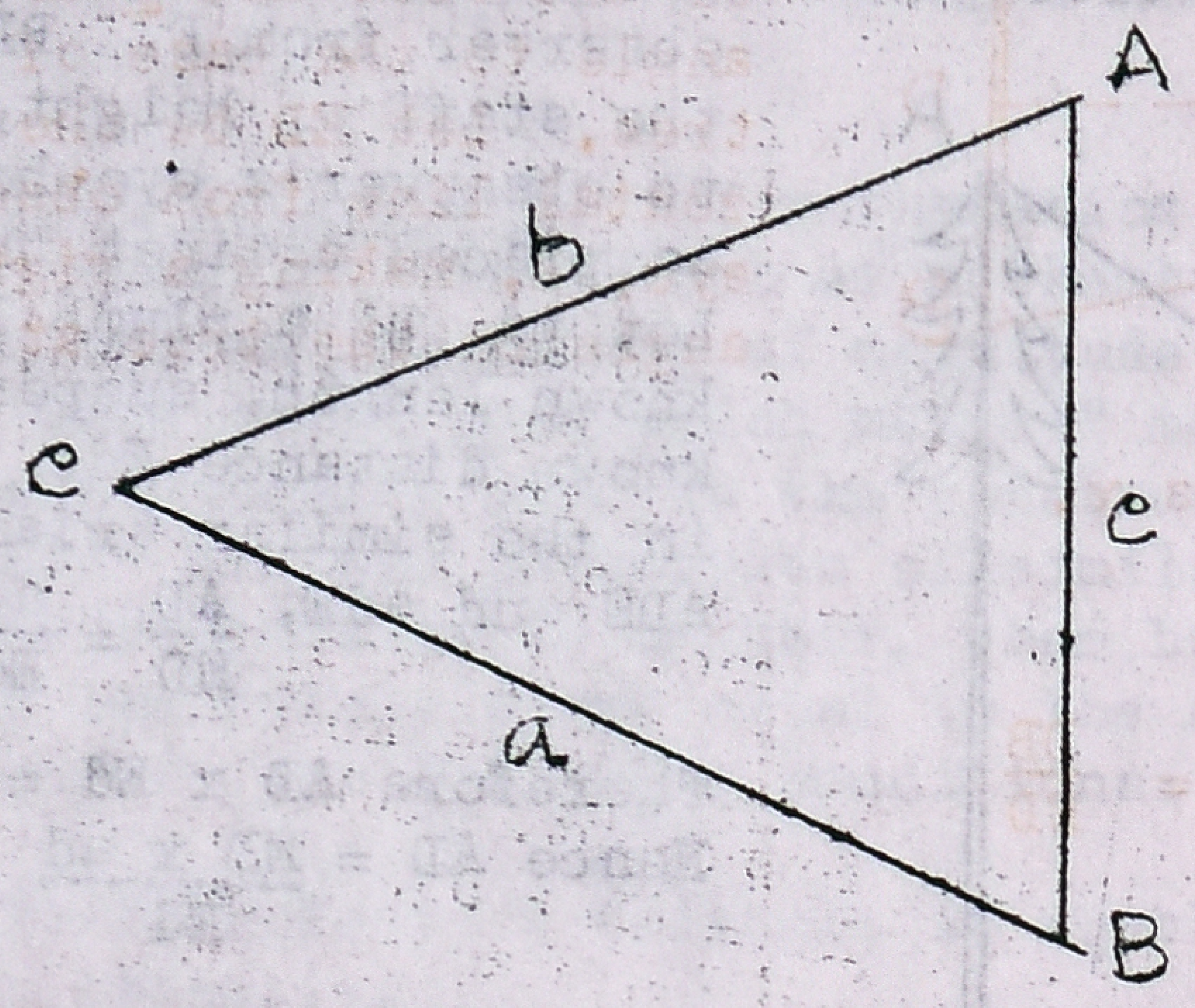
Sine or Sin X = $\frac{\text{Perpendicular}}{\text{Hypotenuse}} = \frac{AB}{AC}$

Cosine or cos X = $\frac{\text{Base}}{\text{Hypotenuse}} = \frac{BC}{AC}$

Tangent or Tan X= $\frac{\text{Sin x}}{\text{Cos x}}$ or $\frac{\text{Perpendicular}}{\text{Base}} = \frac{AB}{BC}$

Assume AB as tree and C as the position of observer. AB can be found out from Tangent Ratio. AB will be Tan X BC . X can be measured with angular instrument and BC can be measured with a Tape. This is known as Tangent method.

9.3 There is another rule in Trigonometry. In any triangle, <u>sines of angles are proportional to the opposite sides.</u> Thus in the triangle ABC in the figure,



$$\frac{\text{Sin } \angle ACB}{c \text{ or } AB} = \frac{\text{Sin } \angle CAB}{a \text{ or } BC} = \frac{\text{Sin } \angle ABC}{b \text{ or } AC}$$

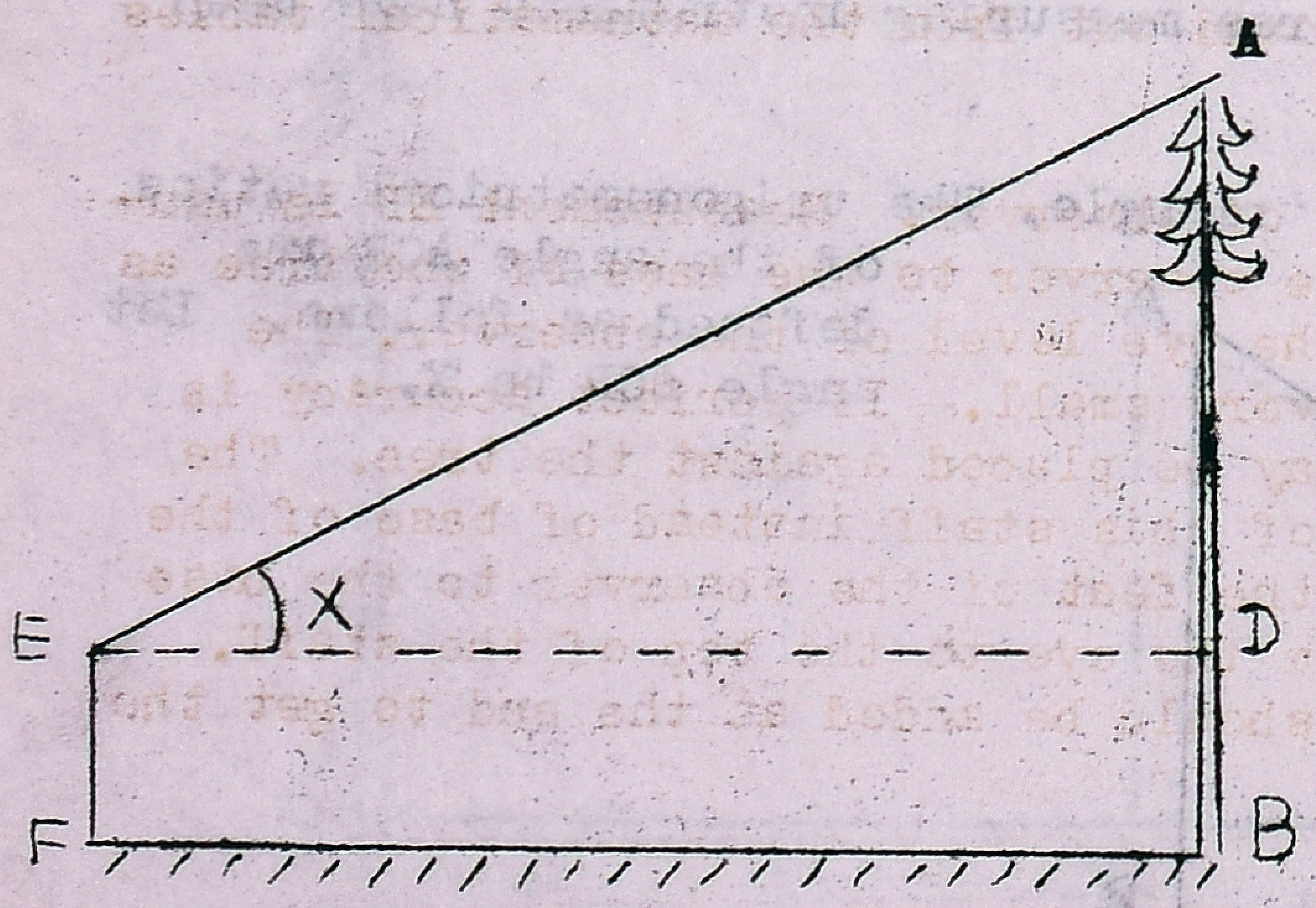
This principle can also be used for calculation of heights of trees and this is known as Sines method.

Thus there are two methods

i) Tangent method and
ii) Sine method.

10.1 <u>Tangent method:</u> Under this method, we can find out the height of trees with the help of tangent of the angles to the top and base of the tree and the distance of the tree from the observer. The observer will have to be in different positions depending upon the terrain of the area. Hence depending upon the position of the observer, the procedure will have to be modified.

10.2 <u>Case 1:</u> <u>On level ground:</u> Let AB be the tree. The observer EF is standing on the same horizontal plane as the trees. Let the angle to the top of the tree i.e. $\angle$ AED be X. In the triangle AED,

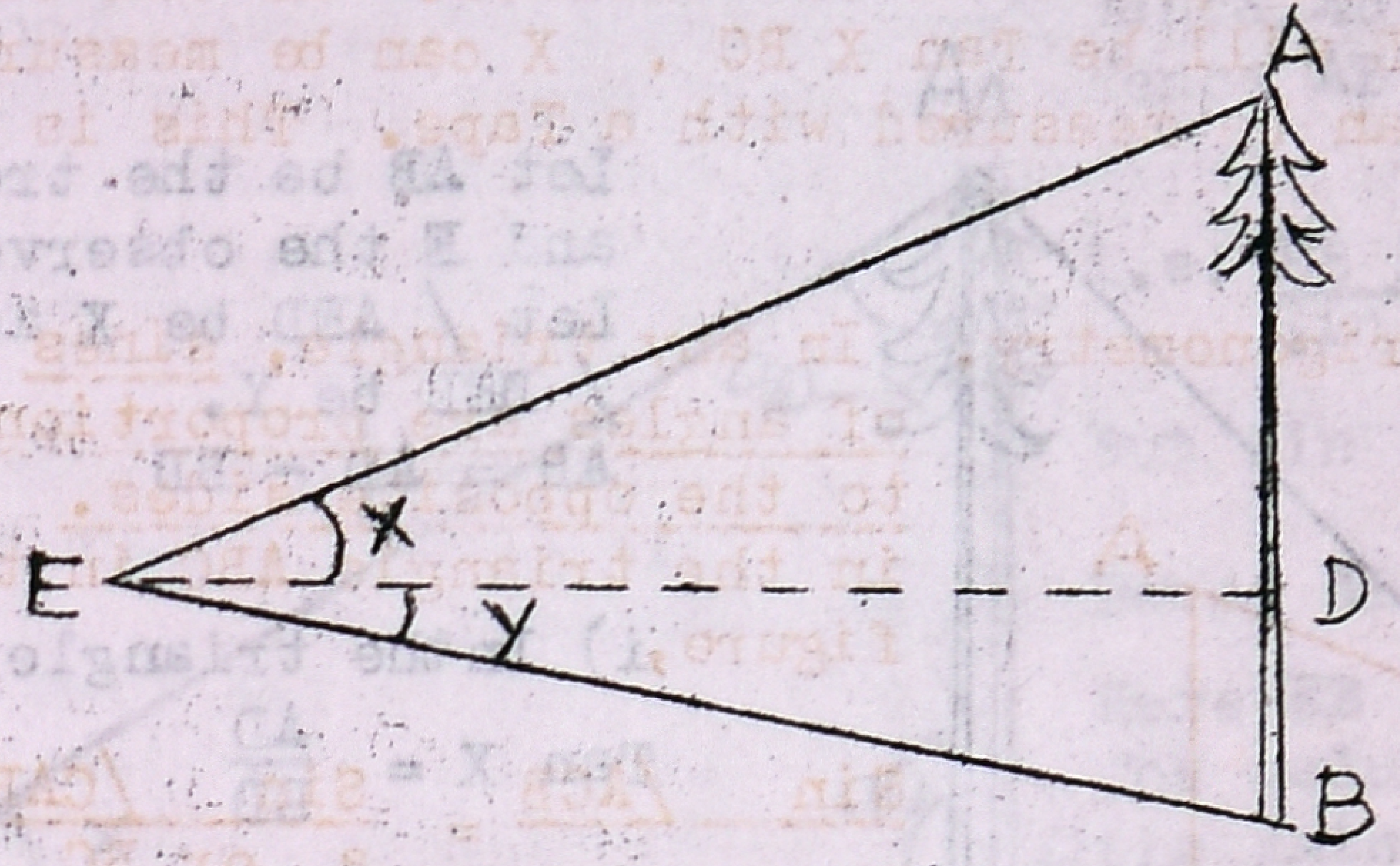


$$\text{Tan } X = \frac{\text{Perpendicular}}{\text{Base}}$$

i.e. $\frac{AD}{ED}$

Hence AD = ED x Tan X
The tree AB = AD + DB.
Hence AB = (ED x Tan X) + DB
Here ED = BF and DB = EF.
Both EF and BF can be measured.

10.3 <u>On sloping ground:</u> <u>The observer is at such a place that the top of the tree is above his eye level and the base of the tree is below his eye level.</u>



i) Let AB be the tree. Let X be the angle to the top of the tree and y be the angle to the base of the tree. Let ED be the horizontal line from observer's eye, E, making a right angle on the tree at D.

Now ∠ AED is X and ∠ DEB is y.

AB = AD + DB

$\text{Tan } X = \frac{AD}{DE}$; $\text{Tan } y = \frac{DB}{ED}$

Hence AD = DE x Tan X;
DB = DE x Tan y.
Hence AD + DB = DE Tan X + DE Tan y
i.e. <u>DE (Tan X + Tan y)</u> .

ii) Supposing D lies at such a high point that measurement of ED is very difficult, we will have to change the procedure as only EB will be measurable.

Take the right angled triangle EDB

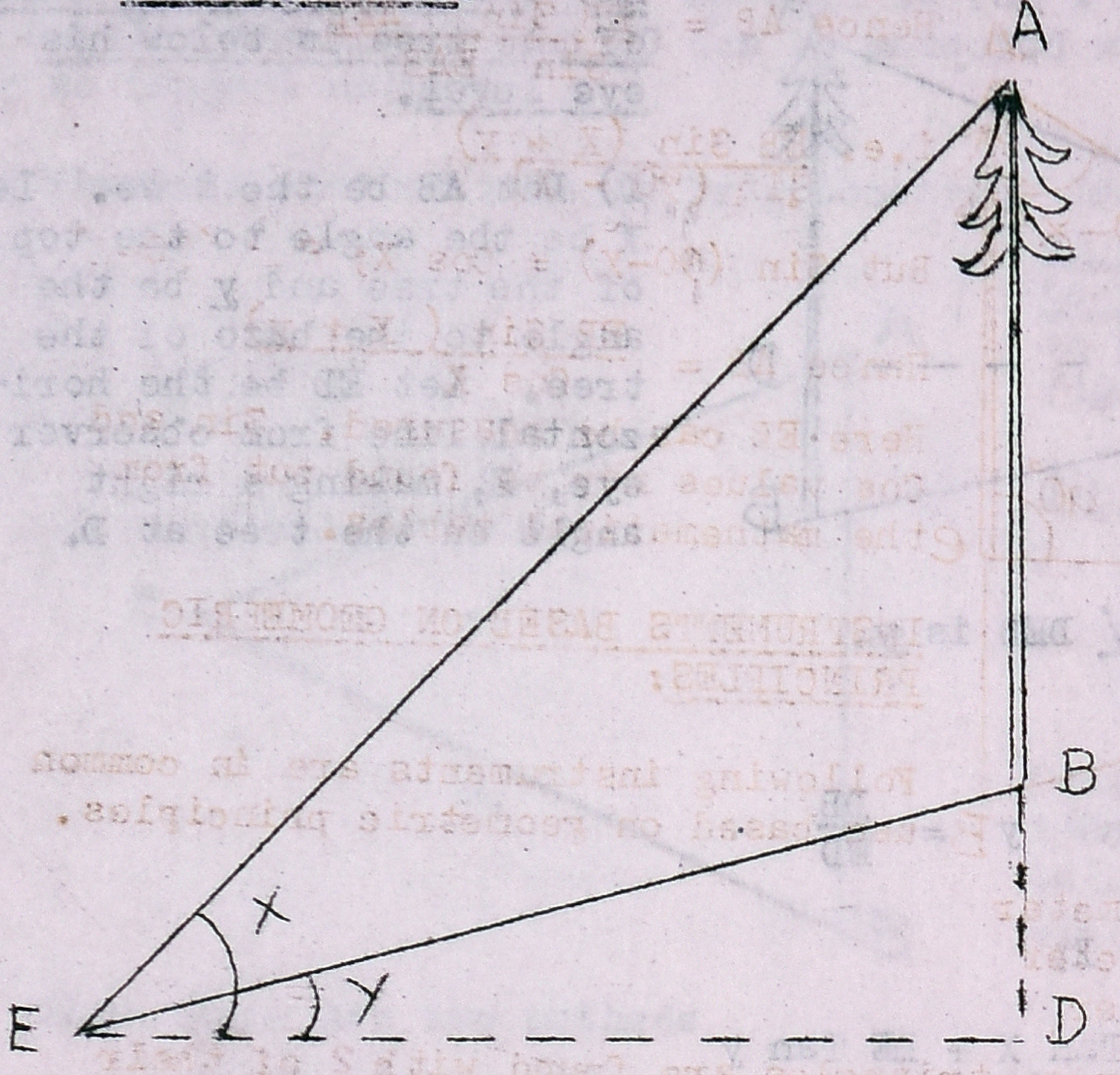
$\text{Cos } y = \frac{\text{Base}}{\text{Hypotenuse}} = \frac{DE}{EB}$

Hence DE = EB x Cos y; substituting EB Cos y for DE, DE (Tan X + Tan y) will become <u>EB Cos y (Tan X + Tan y)</u>.

Tan and Cos values can be found out from the mathematical tables and EB can be measured.

<u>Note:</u> In fact E is the eye level of observer. Measurement EB is usually measured from the feet of the observer to the base of the tree as it is difficult to measure from the eye level of the observer. The error due to this measurement is very small. If perfect accuracy is required, a staff of eye height may be placed against the tree. The angle may be measured to the top of this staff instead of base of the tree. Then the measurement from the feet of the observer to the base will be equal to the distance from the eye to the top of the staff. However, the height of the staff should be added at the end to get the correct height of the tree.

10.4 On sloping ground where the top and base of the tree are above the eye level.



Let AB be the tree and E the observer.
Let ∠ AED be X and ∠ DEB be Y.
AB = AD - BD

i) In the triangle AED,

$\text{Tan } X = \frac{AD}{ED}$

Hence AD = ED Tan X

ii) In Triangle EBD,

$\text{Tan } y = \frac{BD}{ED}$

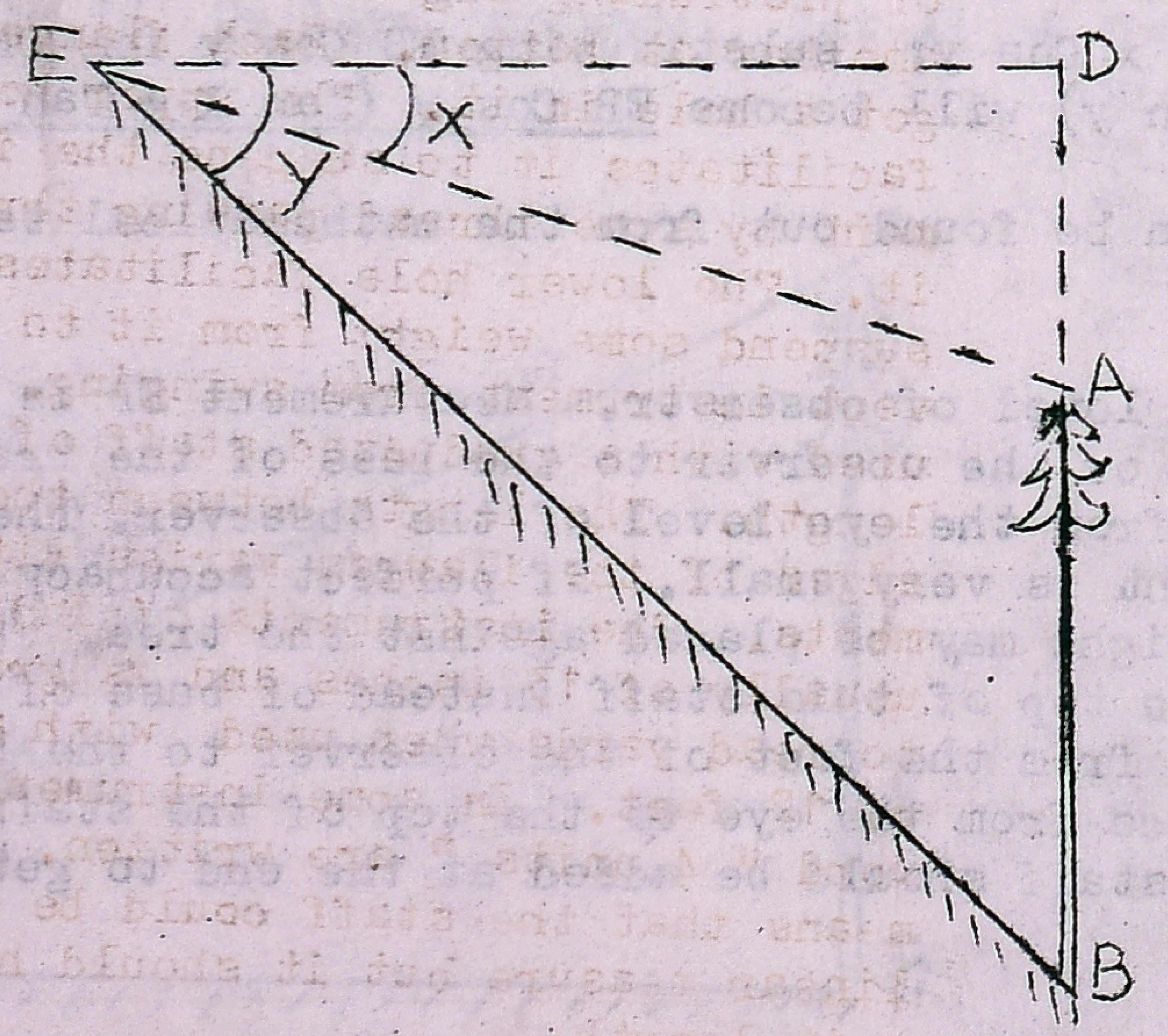
Hence BD = ED Tan y
Since AB = AD - BD;
AB = ED Tan X - ED Tan y

i.e. ED (Tan X - Tan y).

ii) Cos method: If ED is not measurable and only EB can be measured, in the triangle EBD, $\text{Cos } y = \frac{ED}{EB}$

Hence ED = EB Cos y; substituting EB Cos y for ED in ED (Tan X - Tan y), it will be EB Cos y (Tan X - Tan y).

10.5 On sloping ground where base and top of the tree are below eye level.



i) Let AB be the tree, E be the observer's position

∠ DEB = y

∠ DEA = X

AB = BD - AD

$\text{Tan } X = \frac{AD}{ED}$

Hence AD = ED Tan X

Tan y = BD/ED

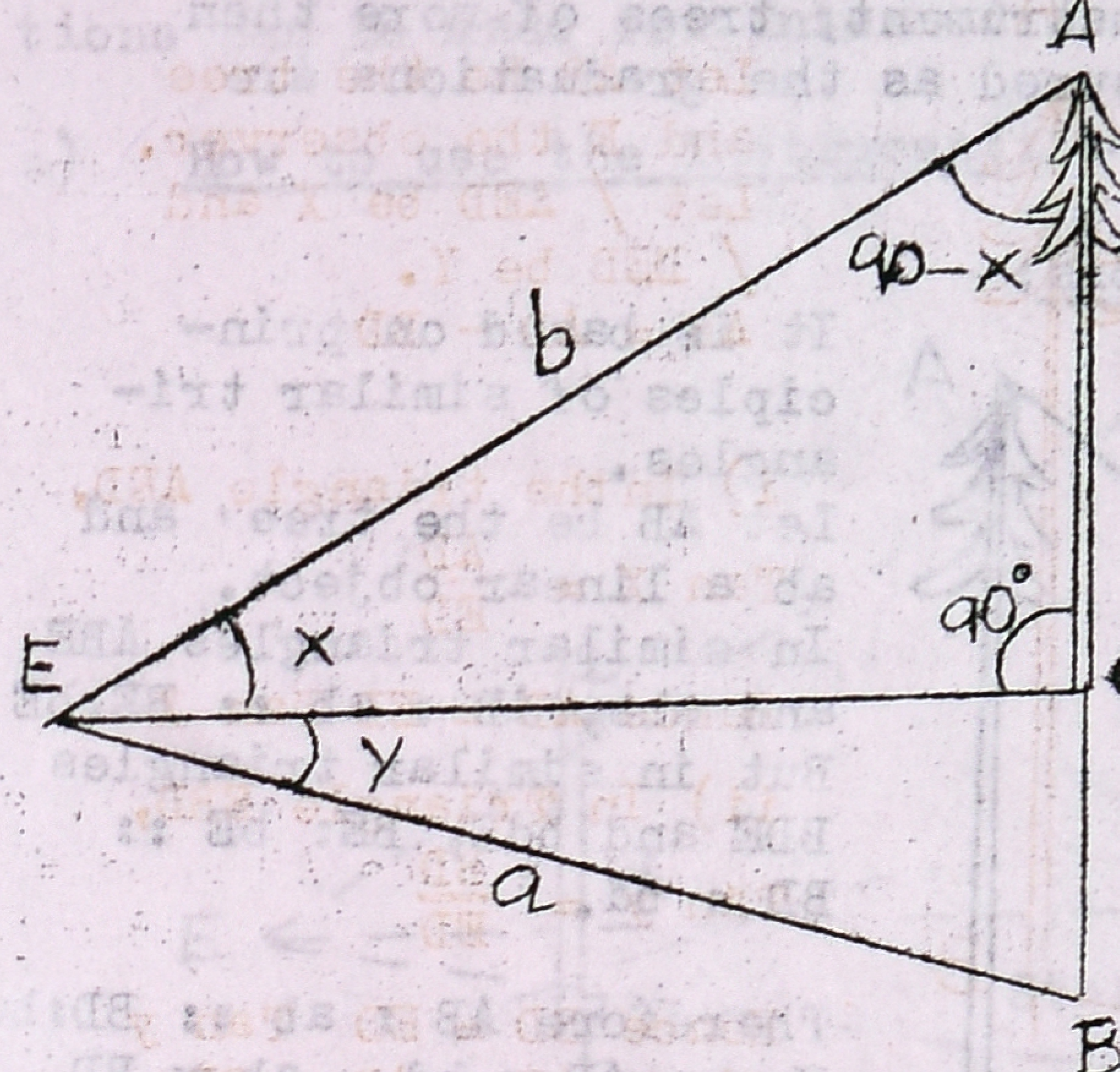
Hence BD = ED Tan y;
AB = BD - AD i.e.
ED Tan y - ED Tan X.

i.e. ED (Tan y - Tan X).

ii) Supposing ED is not measurable and only EB is measurable. Taking the triangle EDB, Cos y = ED/EB.

Hence ED = EB Cos y; substituting EB Cos y for ED, in ED (Tan y - Tan X) it will become EB Cos y (Tan y - Tan X).

11. **Sine method:** Sine Law states, $\frac{\text{Sin AEB}}{AB} = \frac{\text{Sin EAB}}{EB}$



Hence AB (Sin EAB) = EB (Sin AEB);

Hence $AB = \frac{\text{EB Sin AEB}}{\text{Sin EAB}}$

i.e. $\frac{\text{EB Sin }(X + y)}{\text{Sin }(90 - X)}$

But Sin (90-X) = Cos X; [illegible]

Hence $AB = \frac{\text{EB Sin }(X + y)}{\text{Cos } X}$

Here EB can be measured. Sin and Cos values may be found out from the mathematical tables.

INSTRUMENTS BASED ON GEOMETRIC PRINCIPLES:

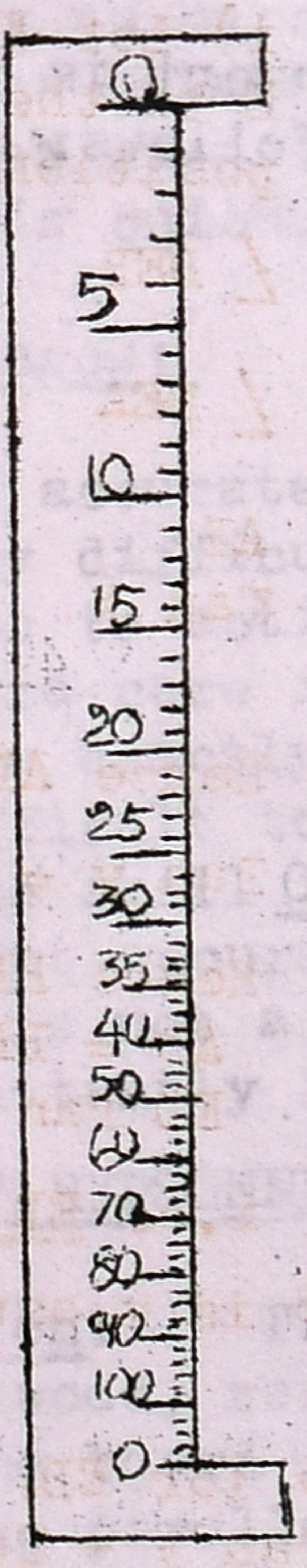
Following instruments are in common use based on geometric principles.

i) Christen's Hypsometer
ii) Smithies' Hypsometer
iii) Weise's Hypsometer

With these instruments, triangles are found with 2 of their sides - one is the tree and the other is the distance from the observer to the tree, and tree height is calculated as explained in para 8. These instruments do not measure any angles.

12. **CHRISTEN'S HYPSOMETER:**

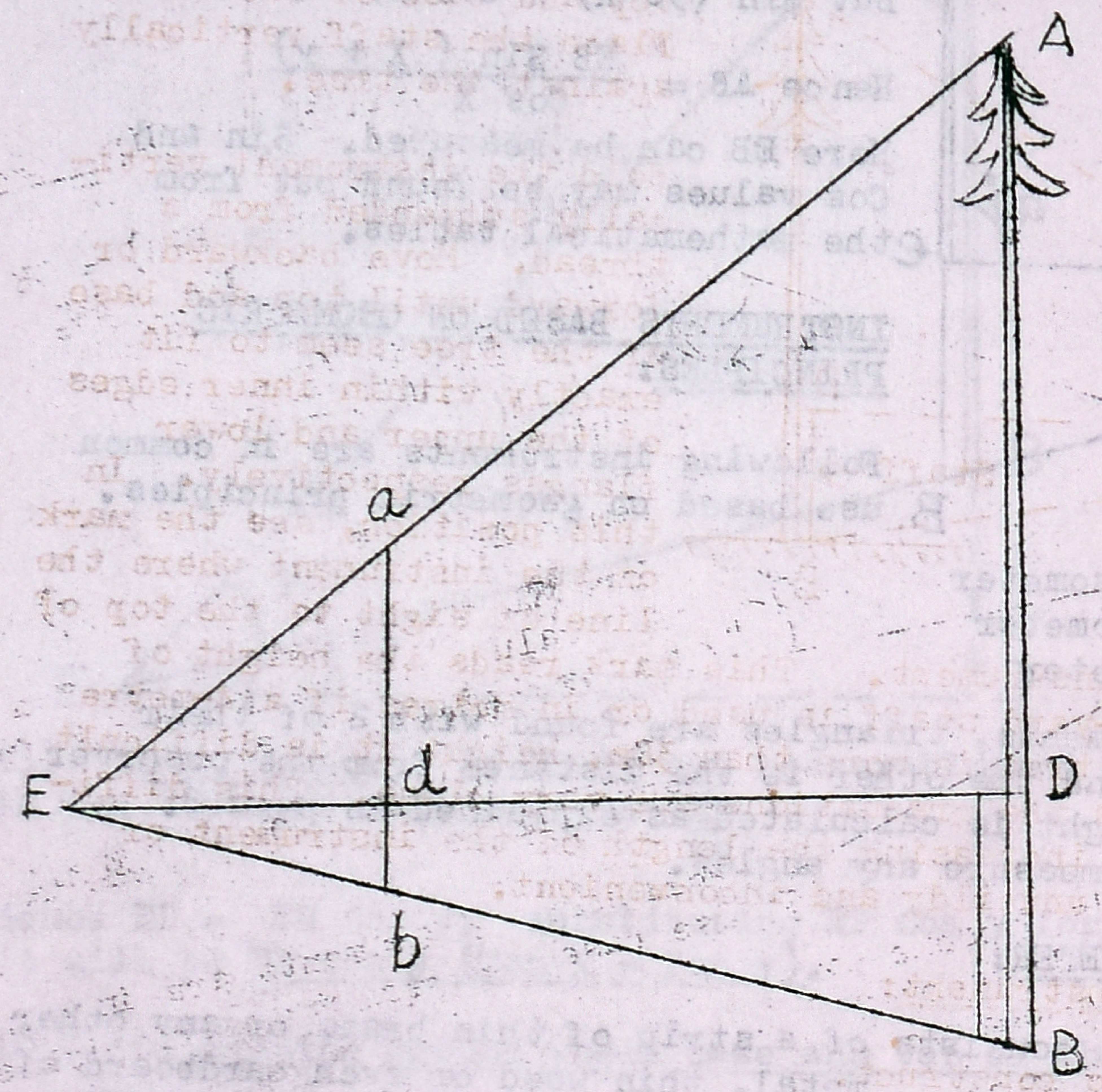
a) **Description:** It consists of a strip of thin brass or any other metal, thin wood or even cardboard of about 2.5cm wide. There are 2 flanges, or protruding edges - one at top and another at bottom. Each flange has got a hole in it. The upper hole facilitates it to suspend the instrument by some thread passing through it. The lower hole facilitates to suspend some weight from it to prevent instrument from swinging. It is used with a graduated staff of known length. The length between the inner edges of the flanges varies with instruments. The instruments of India are usually of 13 inches and is graduated to read yards when used with a staff of 12 feet. In some instruments, the word " 4 units " are written. This means that the staff could be of any linear measure but it should have 4 unit length.



Example: If the staff is of 12 feet long, the instrument will give height in 3 feet or 1 yard. If the staff is of 4m. the instrument will give height in metres. and the length of the instrument will be one metre.

The graduations are wider apart above and closer below. Though all heights can be measured with this instrument, trees of more than 30 metre height are difficult to be measured as the graduations are closer beyond 30 metres.

b) Principle and method of Graduations:



It is based on principles of similar triangles.
Let AB be the tree and ab a linear object.
In similar triangles ABE and abe, AB : ab :: BE:bE
But in similar triangles BDE and bdE, BE: bE :: BD : bd.

Therefore AB : ab :: BD:bd;
Hence AB x bd = ab x BD
Therefore $AB = \frac{ab \times BD}{bd}$

If BD and ab are made constant, AB varies inversely as bd. Based on this principle, the instrument has been graduated. bd has been graduated for different values of AB by using the formula $\frac{BD \times ab}{AB}$.

Example: If AB is 5 metres, length of the instrument is 30cm and length of the post or staff is 4 metres, bd will be as follows:

$$AB = \frac{ab \times BD}{bd}$$

i) 5m or 500 cm $= \frac{30 \times 400}{bd}$

$500 \times bd = 30 \times 400$

$bd = \frac{30 \times 400}{500} = 24$ cm.

ii) Similarly if AB is 10m, 1000 $= \frac{30 \times 400}{bd}$

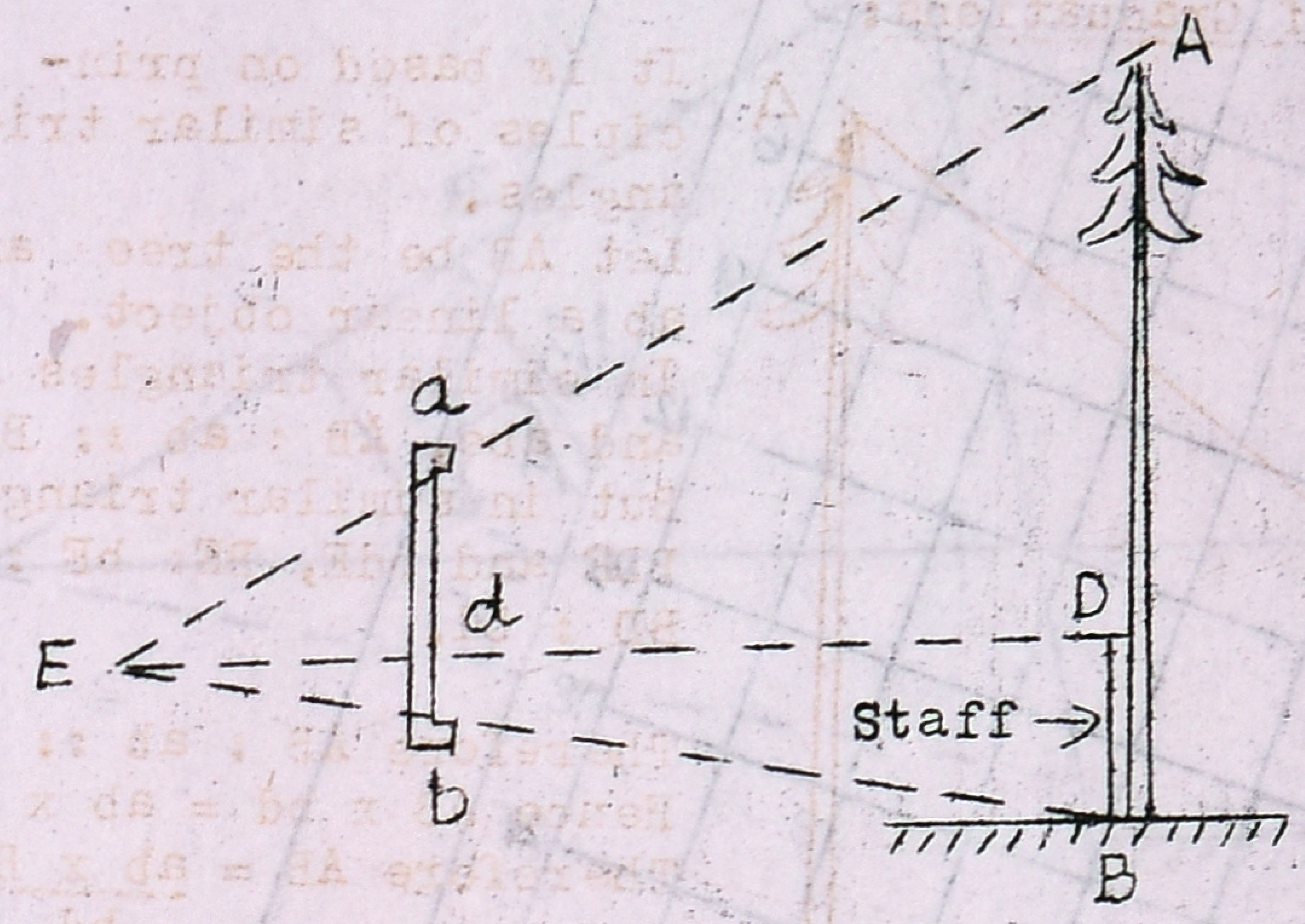
$bd = \frac{30 \times 400}{1000} = 12$ cm.

iii) Similarly for 15m, it is 8 cm.
iv) Similarly for 20m, it is 6 cm.
v) Similarly for 25m, it is 4.8 cm.
vi) Similarly for 30m, it is 4 cm.
vii) Similarly for 35m, it is 3.48 cm.
viii) Similarly for 40m, it is 3cm. and so on.

Note: The difference in length of the instrument between 5m and 10m is 12cm. But the difference goes on diminishing. The difference between 25m and 30m is only 0.8m.

Hence the instrument will be so graduated as to read 10, 15, 20, 25, 30, 35 and 40m. at distances of 12, 8, 6, 4.8, 4, 3.48 and 3 cm respectively, measured from the bottom of the instrument. Similar graduations can be made for intermediate as well as higher values of AB.

c) How to use the instrument: AB is the tree; ab is the instrument. Stand at suitable place E so that you can see both top and base of the tree. Place the staff vertically against the tree.



Hold the instrument vertically suspended from a thread. Move backward or forward until top and base of the tree seem to fit exactly within inner edges of the upper and lower flanges respectively. In this position, see the mark on the instrument where the line of sight to the top of the staff intersect the instrument. This mark reads the height of the tree in yards if a 4-yard staff is used or in metres if a 4-metre staff is used. When the tree is more than 30m. height it is difficult to read the instrument as the graduations are very close. This difficulty can be overcome by increasing the length of the instrument or staff but it will become unweildy and inconvenient.

d) Advantages of the Instrument:

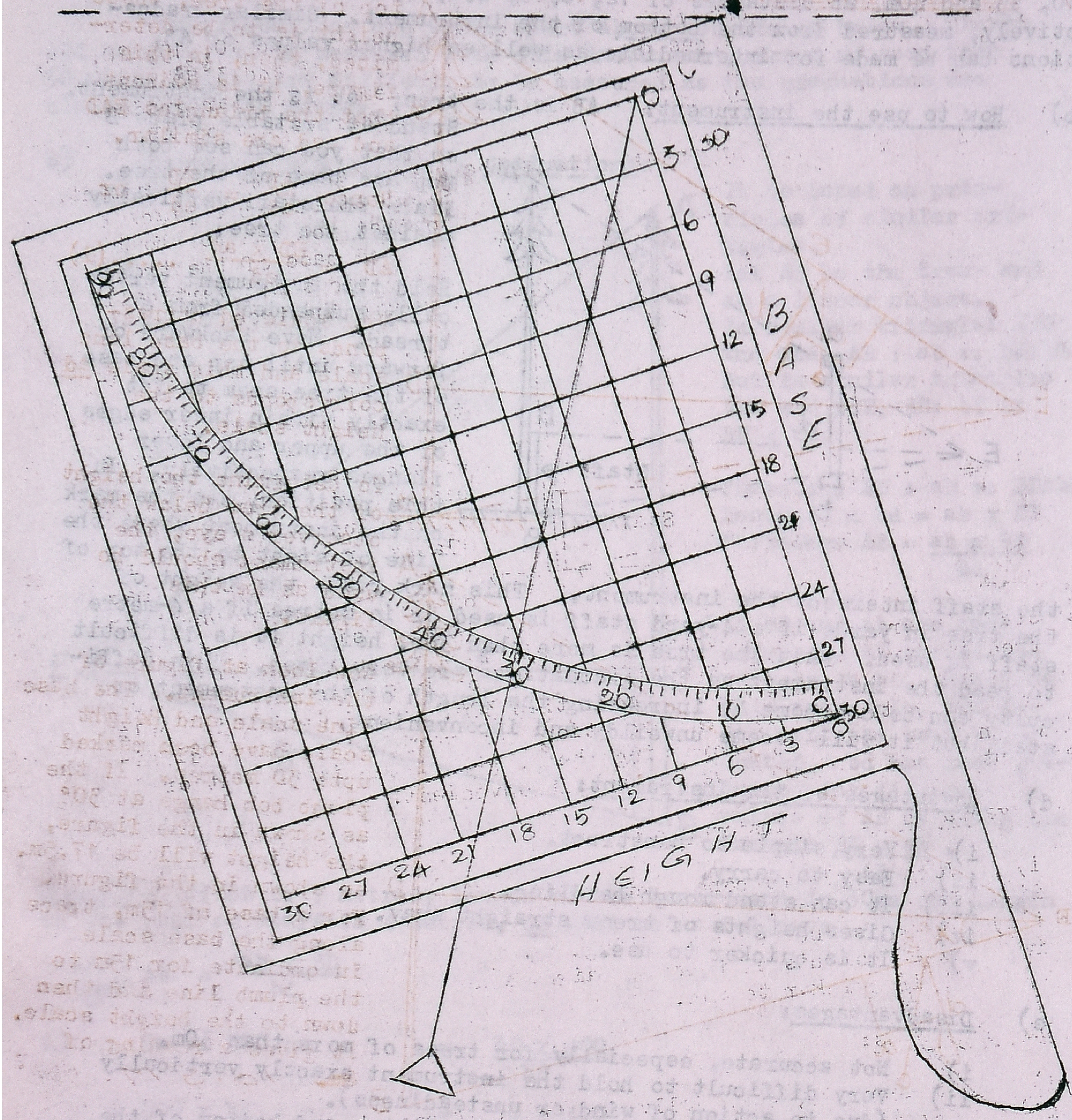
i) Very simple to construct.
ii) Easy to carry.
iii) It can stand rough handling.
iv) Gives heights of trees straight away.
v) It is quicker to use.

e) Disadvantages:

i) Not accurate, especially for trees of more than 30m.
ii) Very difficult to hold the ~~instrument~~ instrument exactly vertically (due to action of wind or unsteadiness).
iii) Extra care is required to hold the top and bottom of the tree exactly within the flanges while reading the heights.
iv) Difficult to carry the long staff in the forests.
v) Some skill is necessary to use the instrument with consistent accuracy.
vi) It is not adapted to steady work due to fatigue caused by constantly holding out arm in the required position.

13. SMYTHIES' HYPSOMETER:

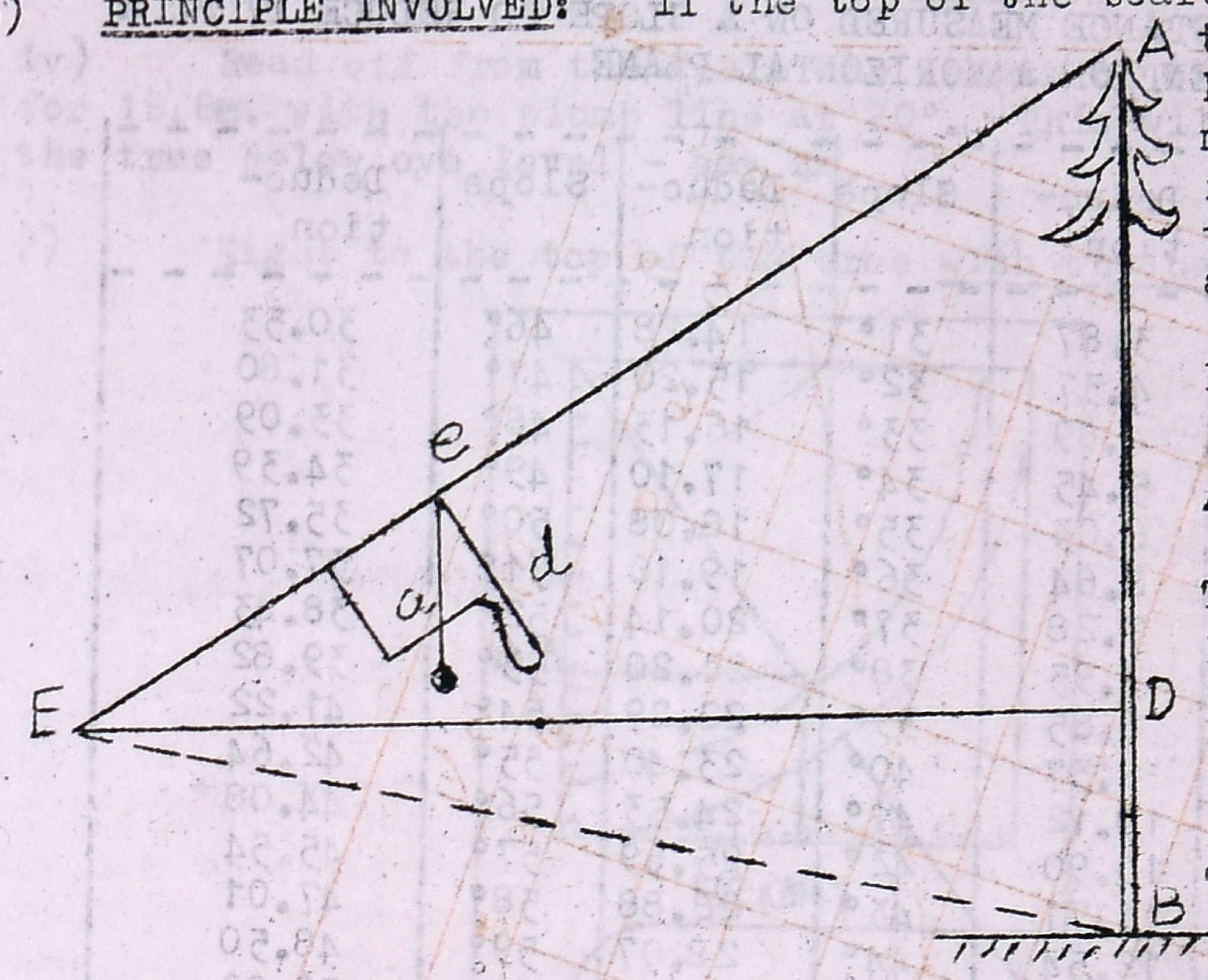
Description: The instrument consists of a flat card board or thin sheet of wood, rectangular in shape, provided with a handle. On one side of the board is pasted a piece of squared paper, with the squares running parallel to the edges of the board and of size to give 10 large squares in each direction so that each square represents 3m or 10 feet. If necessary, each of the small square may be further



divided into 4 divisions so that each sub division may show 0.25 metre. The vertical scale is known as Base scale or distance scale and is graduated from top to bottom. The horizontal scale is called the height scale and is graduated from the side of the handle to the outside. A plumb bob hangs from the top corner towards the handle side of the square paper. A part of the protractor is marked on the squared paper, showing angle from 0° to 90°. This will show the angle made by the plumb-bob with the vertical. This will be the same angle at which the board is held to the horizontal while sighting the tip or the base of the trees.

On the other side of the board, a table has been pasted. This will give the percentage deductions corresponding to different angles of depression or elevation. This will be applied to the sloping distances for finding out the horizontal distance.

b) **PRINCIPLE INVOLVED:** If the top of the board is pointed to the top of the tree, whose height is to be determined, then, in this figure, it is evident that the triangles EAD and ead are similar.

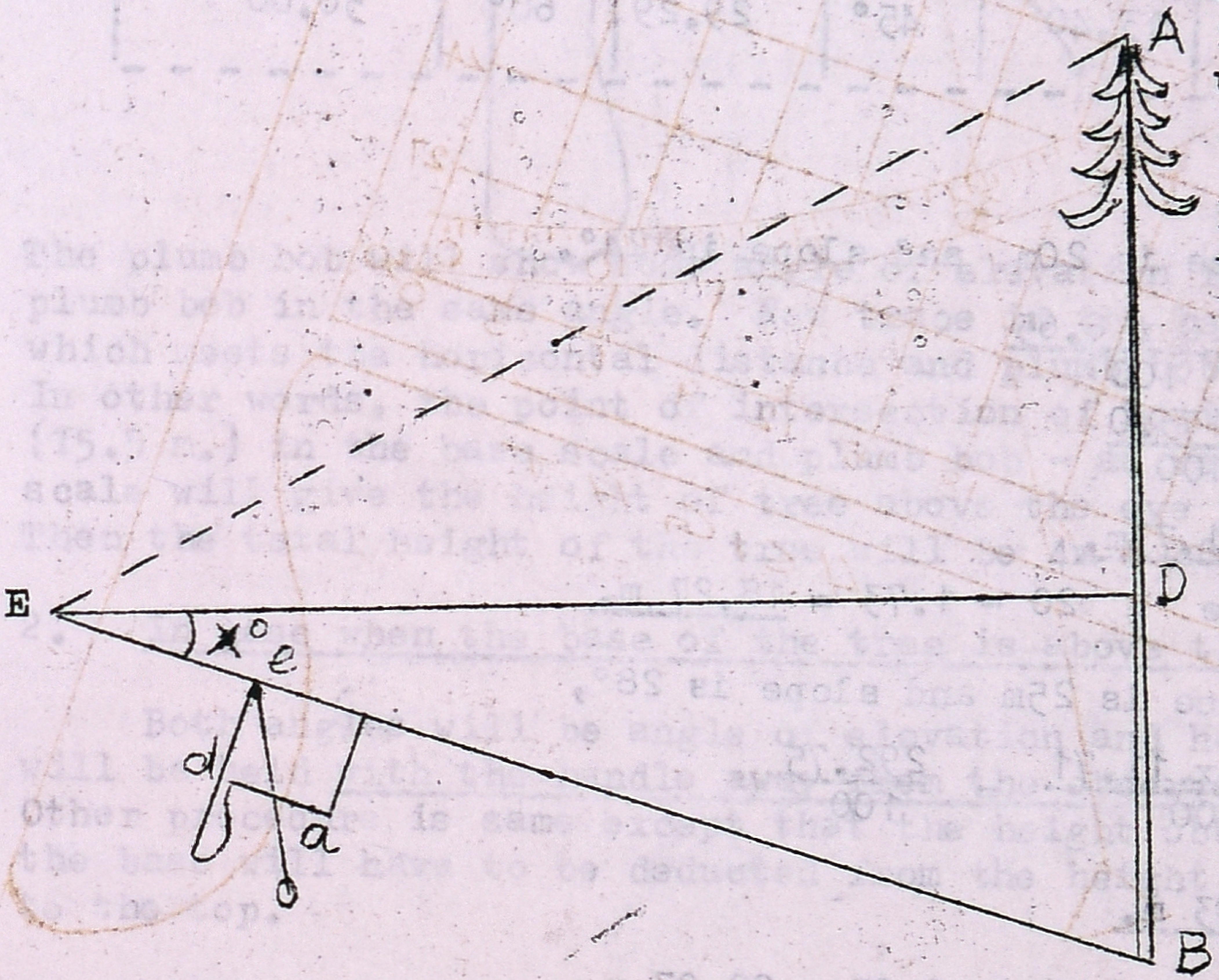


Hence $\frac{AD}{ad} = \frac{ED}{ed}$ or

$$AD = \frac{ED \times ad}{ed} \quad .....(i)$$

The scale ed corresponds to the base line scale and this scale ad corresponds to the height scale.

To determine the height of the tree below the observer's eye, the instrument should be used as in this figure.



Now look at figure of the instrument. The base line scale and height scale have been marked upto 30 metres. If the plumb bob hangs at 30° as shown in the figure, the height will be 17.5m. as shown in the figure. For a base of 15m, trace along the base scale in ordinate for 15m to the plumb line and then down to the height scale. It gives a reading of ~~8m~~ 10.5 M.

According to equation (i), we have to measure the distance from the observer to the tree. To obviate this measurement, the protractor is marked on the squared paper. When the instrument is pointed to the base of the tree, the position of the plumb line will give the angle of depression X. Now we can measure the distance from the observer to the tree along the ground i.e. measure EB instead of ED (from the feet of the observer to the base of the tree and not from eye level).

Relationship between EB and ED is:-

$\text{Cos } X = \frac{ED}{EB}$ Hence $ED = EB \text{ Cos } X.$

On the back of the instrument there will be a table based on equation ED = EB Cos X. Hence ED will always be less than EB and the table will show the percentage to be deducted from EB to get ED. A copy of the table is given below:

DEDUCTION PERCENT OF A DISTANCE MEASURED ON A SLOPE TO REDUCE IT TO A MEASUREMENT ON A HORIZONTAL PLANE

Slope	Deduction	Slope	Deduction	Slope	Deduction	Slope	Deduction
1°	0.02	16°	3.87	31°	14.28	46°	30.53
2°	0.06	17°	4.37	32°	15.20	47°	31.80
3°	0.14	18°	4.89	33°	16.13	48°	33.09
4°	0.24	19°	5.45	34°	17.10	49°	34.39
5°	0.38	20°	6.03	35°	18.08	50°	35.72
6°	0.55	21°	6.64	36°	19.10	51°	37.07
7°	0.75	22°	7.28	37°	20.14	52°	38.43
8°	0.97	23°	7.95	38°	21.20	53°	39.82
9°	1.23	24°	8.65	39°	22.29	54°	41.22
10°	1.52	25°	9.37	40°	23.40	55°	42.64
11°	1.84	26°	10.12	41°	24.53	56°	44.08
12°	2.19	27°	10.90	42°	25.69	57°	45.54
13°	2.56	28°	11.71	43°	26.88	58°	47.01
14°	2.97	29°	12.54	44°	28.07	59°	48.50
15°	3.41	30°	13.40	45°	29.29	60°	50.00

Example:

i) Suppose the distance is 20m. and slope is 24°.

Then deduction = $\frac{20 \times 8.65}{100}$

ie $\frac{173.0}{100}$

i.e. 1.73m.

Horizontal distance = 20 - 1.73 = 18.27 m.

ii) Suppose the distance is 25m and slope is 28°,

Deduction = $\frac{25 \times 11.71}{100}$ = $\frac{292.75}{100}$

i.e. 2.93 m.

Horizontal distance = 25 - 2.93 = 22.07 m.

c) How to use the Instrument?

1) When the top of the tree is above and base is below your eye level:

i) Stand at a convenient place from where you can see the tip and the base of the tree. Measure this distance (from the tree to your feet) along the ground. Let it be 22m.

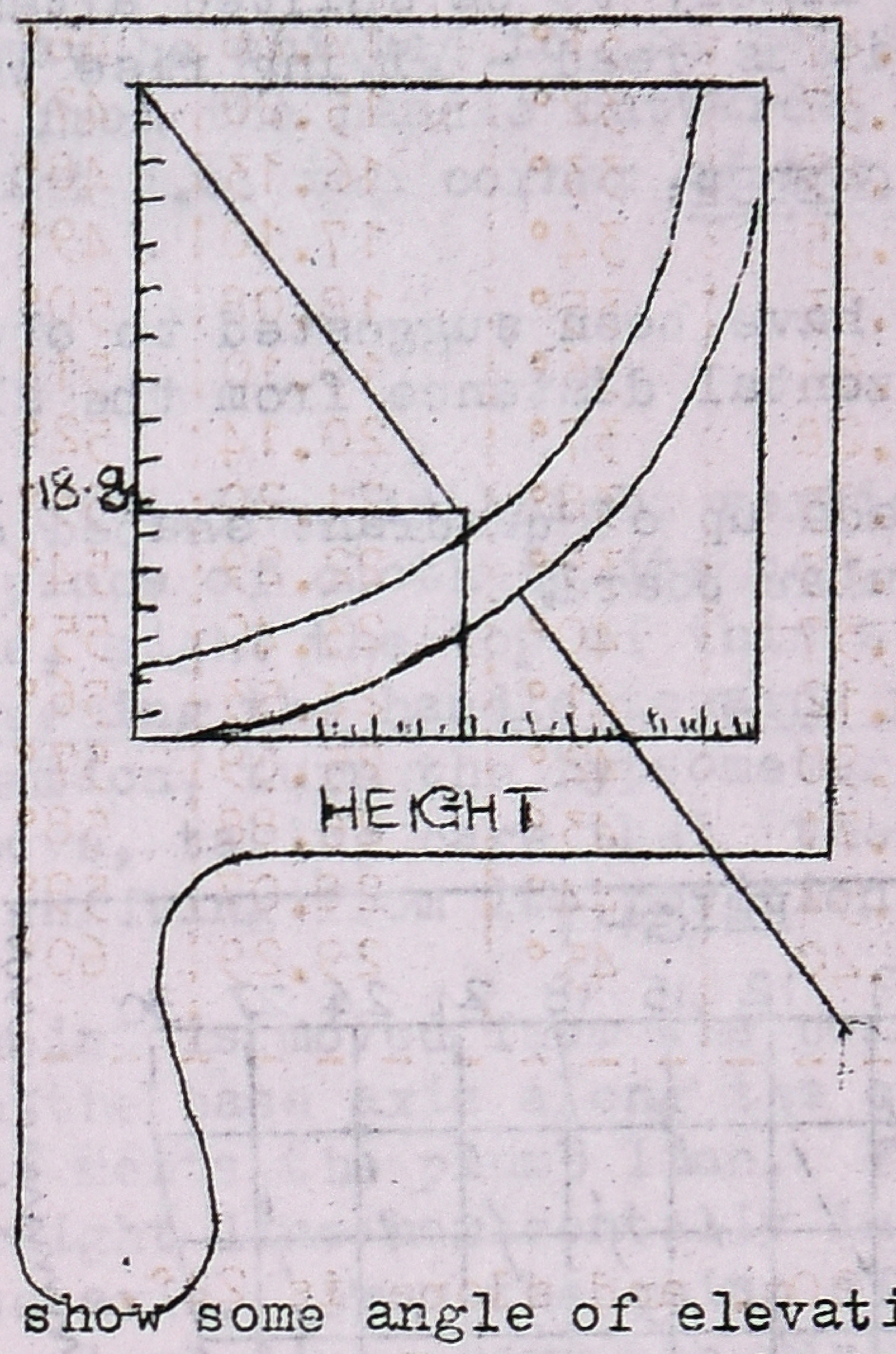
ii) Point the instrument to the base of the tree as shown in the figure with the handle towards you. Read the angle of depression and record it. Let it be 20°.

iii) For this angle of depression find out the percentage of deduction from the table. This comes to 6.03%. Hence the deduction for 20m. will be $\frac{20 \times 6.03}{100}$ i.e. $\frac{12.06}{100}$ i.e. 1.20 metres. Hence the

horizontal distance is 20 - 1.20 = 18.8m.

iv) Read off from the scale the length of the tree below eye level for 18.8m. with the plumb line at 20°. This will give you the height of the tree below eye level - say 4m.

v) Sight to the top of the tree with the handle away from you.



The plumb bob will show some angle of elevation from E. Hold the plumb bob in the same angle. Now trace in the height scale the point which meets the horizontal distance and plumb bob along the ordinate. In other words, the point of intersection of horizontal distance (15.5 m.) in the base scale and plumb bob - as read in the height scale will give the height of tree above the eye level. Let it be 20m. Then the total height of the tree will be 4m + 20m = 24m.

2. In case when the base of the tree is above the eye level:

Both angles will be angle of elevation and hence the instrument will be held with the handle away from the observer in both cases. Other procedure is same except that the height obtained by sighting the base will have to be deducted from the height obtained by sighting to the top.

3. In case the whole tree is below the eye level: Both angles will be depression. Hence the instrument will have to be held with the handle towards the observer in both the cases. The height obtained by sighting to the top will have to be deducted from the height obtained by sighting the base.

d) Advantages:

i) Cheap and easy to construct
ii) Easy to carry
iii) Horizontal distance can be deducted from the sloping distance without separate reference to mathematical tables.
iv) There are no intricate adjustments to be made.
v) Measurements are comparatively quicker.

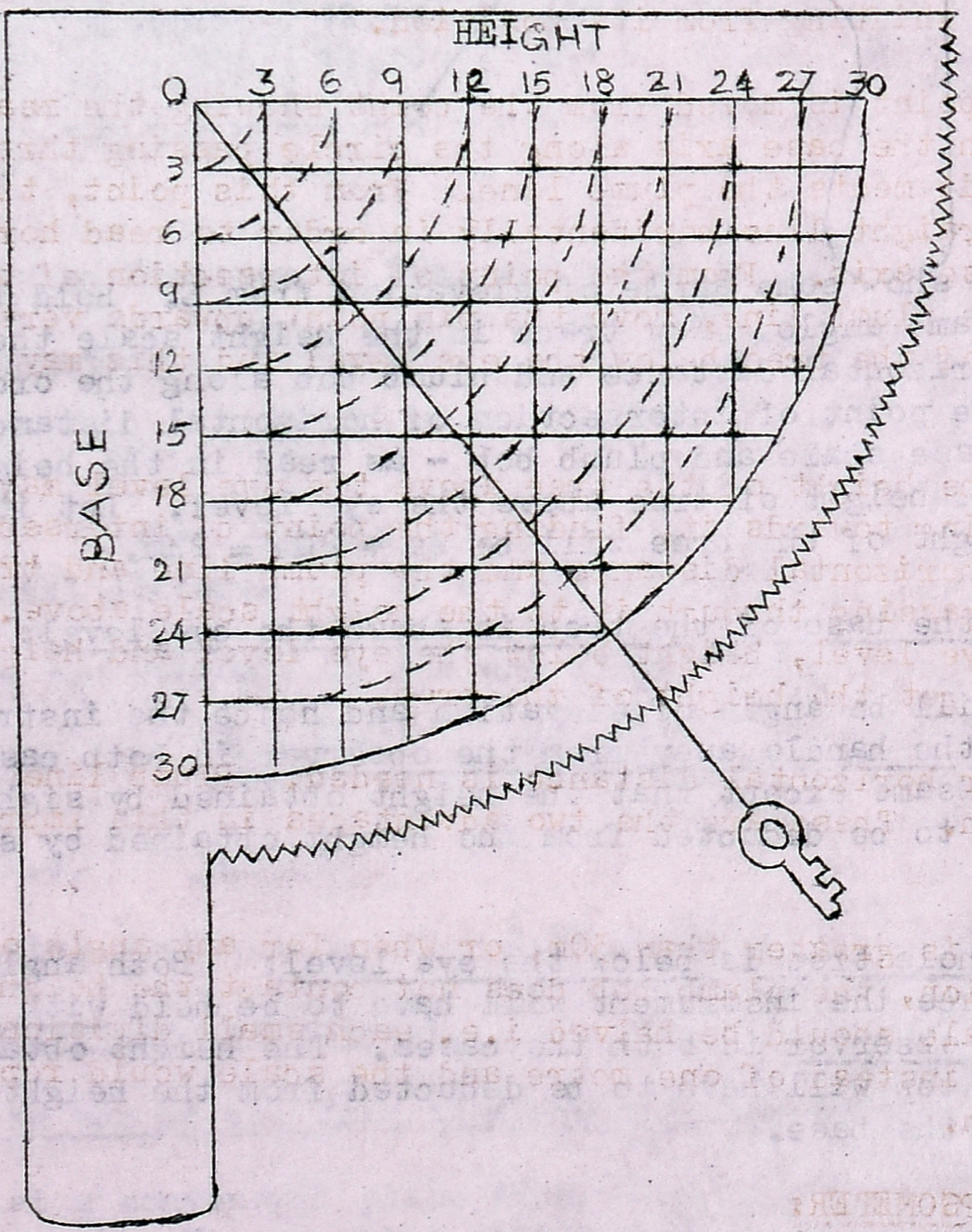
e) Disadvantages:

i) Cannot be used on windy or rainy days. The tables pasted will all be washed off.
ii) They are not very precise as smallest division represents 3m.
iii) Error will be greater if trees are taller than 30m.
iv) Plumb bob line is likely to be shifted after measuring the angle and before it is read - giving rise to error.

14. MODIFIED SMYTHIES' HYPSOMETER:

Following modifications have been suggested to obviate the necessity of finding out the horizontal distance from the sloping distance.

i) The instrument may be made up of quadrant shaped card board with a handle instead of a rectangular board.



ii) The outer rounded face will be provided with conspicuous numerous small teeth so that each tooth will represent one degree.

iii) With the top corner of the graph paper as centre, quarter circles are drawn from the corner upto the end of the base and height axis at every 2 or 3m mark interval. If bigger graph sheets are used, the marks can be drawn for every metre interval.

iv) Height axis may be shifted to the top straight edge of the graph paper and graduated from the handle outwards, thus making zero of both axis at the same point i.e. top corner of the graph paper towards the handle.

USE OF INSTRUMENT:

Keep a staff of 1.37m. in height vertically at the base of the tree. Tie a small piece of cloth to its top. Instead of sighting at the base of the tree, sight the top of this staff along the upper edge of the instrument keeping the handle towards you. When the plumb bob is in a constant position, turn the hypsometer, to a side, keeping the graph paper face above, taking care that the plumb bob is caught in same tooth without shifting from its position.

Then a pin point is moved from the point showing the measured sloping distance on the base axis along the circle passing through that point, until it meets the plumb line. From this point, turn backwards along the straight line horizontally in order to read horizontal distance on the base axis. From the point of intersection of the curved line and the plumb line, move the pin point upwards vertically to get the height of the tree below the eye level and this may be noted down.

Similarly the height of the tree above the eye level may be found out by sighting towards it, finding the point of intersection of the determined horizontal distance and the plumb line and tracing the vertical line passing through it to the height scale above. The height above the eye level, height below the eye level and height of staff are added to get the height of the tree.

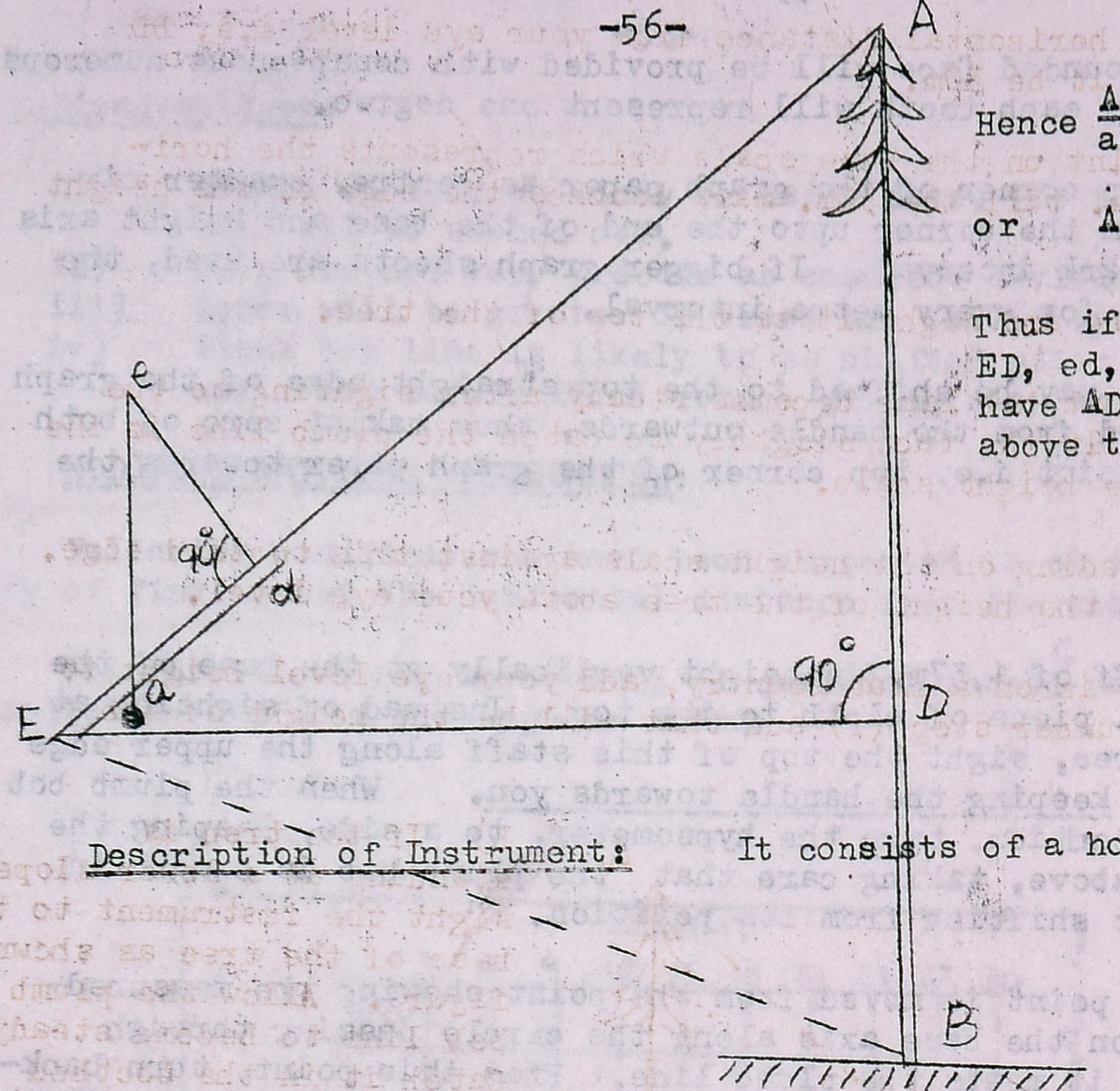
No table for horizontal distance is needed. Plumb line is caught in the teeth. These are the two advantages in this improved variety.

If the base is greater than 30m, or when for any angle of depression or elevation, the plumb bob does not contact the height scale, both the scale should be halved i.e. each small division will represent 2 metres instead of one metre and the scale would represent 60m. instead of 30m.

15. WELSE'S HYPSOMETER:

i) PRINCIPLE: As before, E is the observer's eye. AB is the tree. ED is the horizontal through E.

If, through any point d on EA we draw a perpendicular to EA of length ed and from e suspend a plumb line ea cutting EA at a, we have the triangles EAD and ead are similar.

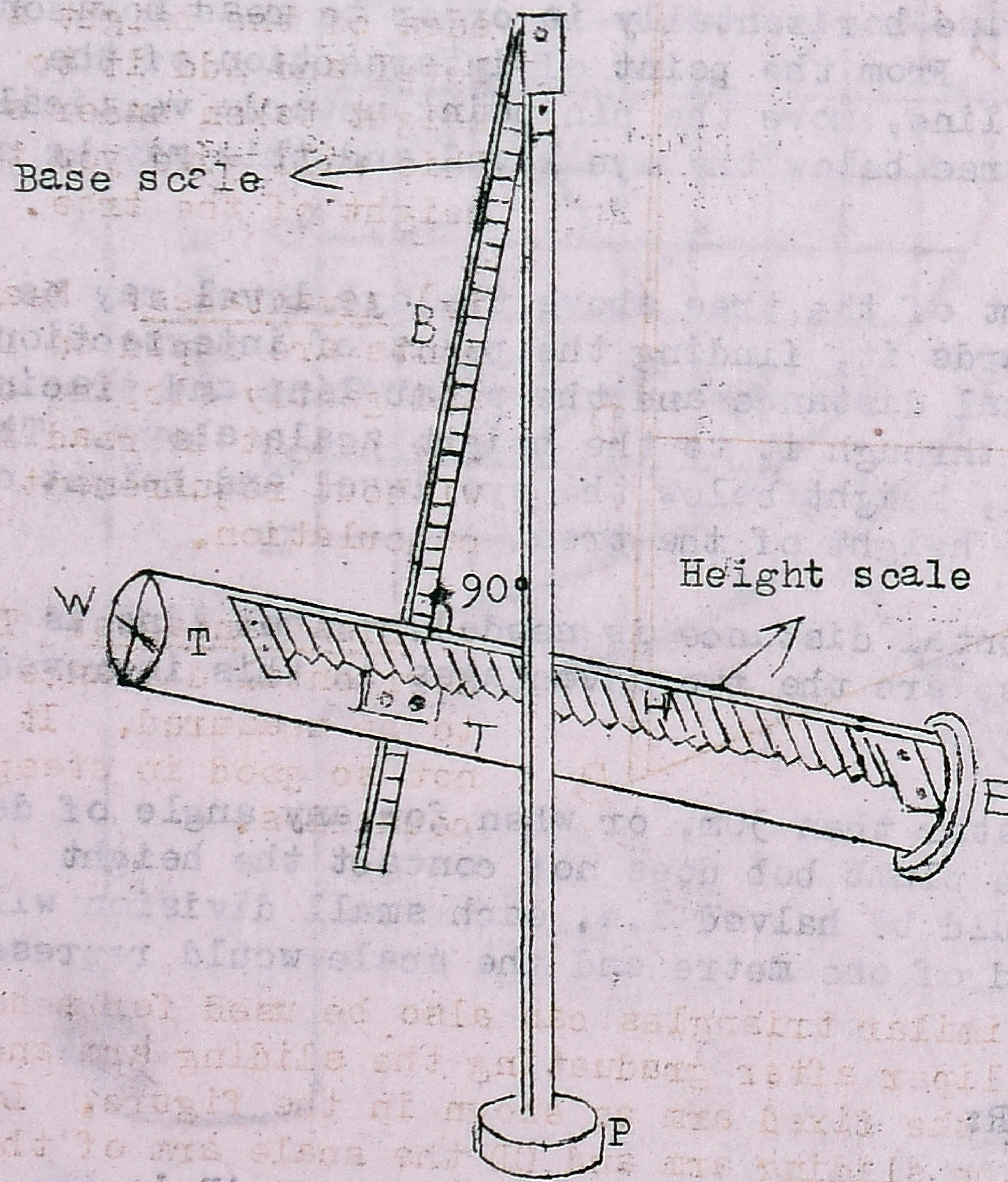


Hence $\frac{AD}{ad} = \frac{ED}{ed}$

or $AD = \frac{ED}{ed} \times ad.$

Thus if we can measure ED, ed, and ad, we can have AD -- the height above the eye level.

ii) Description of Instrument: It consists of a hollow tube T with an eye piece E at one end and cross wire W at the other end.



A moveable scale B, called the base line scale, is attached to the tube so that it can be pulled out to any required distance and at the same time remains perpendicular to the tube T.

Another scale called the height scale is fixed along the tube itself. This scale has toothed edges, in order to catch a plumb-bob which hangs from the top of the base line scale. When not in use, the base line scale and plumb bob are kept in the tube. The two scales are graduated in equal and the same small graduations.

iii) How used?

a) Station yourself at a convenient point, say E with reference to the tree say AB in the sketch.

b) Measure the horizontal distance from your eye level i.e. BD in the sketch; let it be 30m.

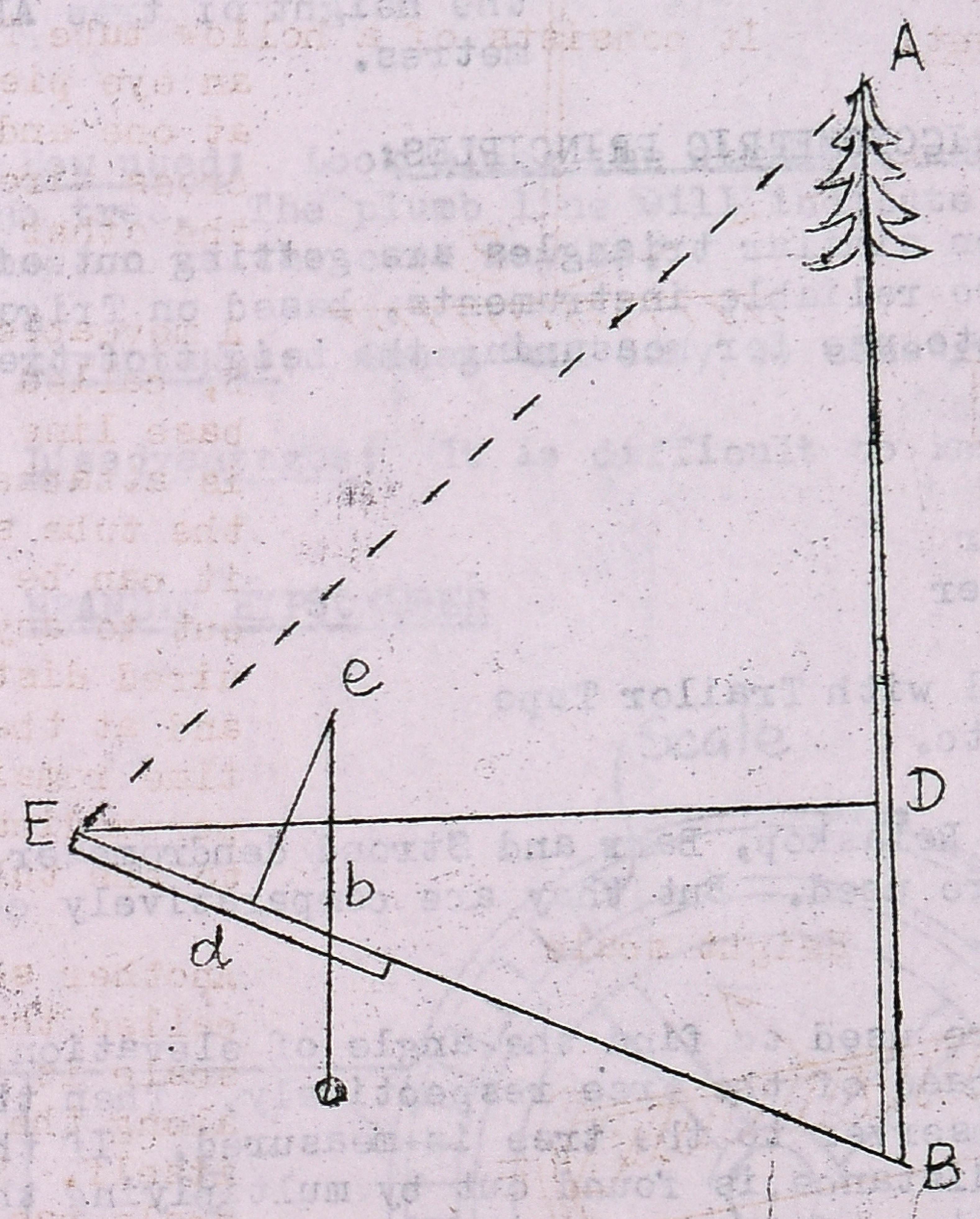
c) Mark the point on the base scale which represents the horizontal distance i.e. till the 30m. mark touches the edge of the height scale.

d) Turn the tube and sight it to the top of the tree.

e) When the plumb bob line becomes steady after sighting to the top of the tree, tilt the tube slightly to catch the plumb line in the toothed edge of the height scale.

f) Take the reading on the height scale against this toothed edge. This reading gives the height of the tree above your eye level.

g) If the tree is on a flat country, add your eye level height to the reading taken under step (f) and that will be the height of the tree.



h) If the tree is standing at a lower slope, sight the instrument to the base of the tree as shown in figure. Allow the plumb bob line to become steady. Catch it in the toothed edge of the height scale level and add it to the height taken under step(f). This will give you the height of the tree.

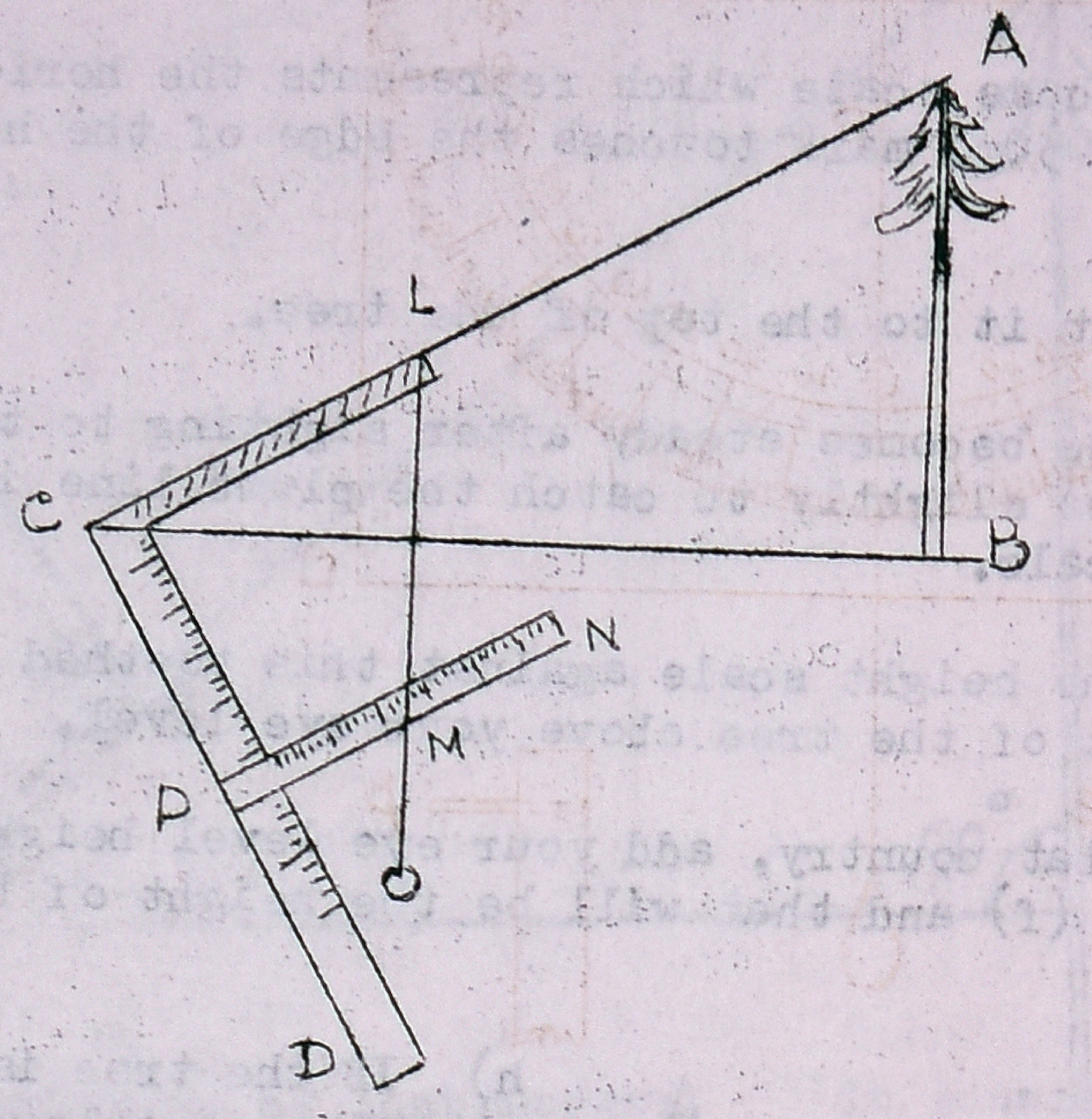
iv) __Advantages:__ Measurements are rapid on flat and gently sloping country. The height is read directly without requirement of calculation.

v) __Disadvantages:__ The horizontal distance has to be measured. It is not so good in steep countries.

16. __IMPROVISED CALLIPERS:__

The principle of similar triangles can also be used for measuring heights even by a calliper after graduating the sliding arm and attaching a plumb line to the fixed arm as shown in the figure. Let CL be the fixed arm, PN the sliding arm and CD the scale arm of the calliper. Let AB be the tree whose height is to be measured.

The calliper may be opened out to keep the sliding arm to read centimetres on scale arm equal to distance of observer from the base



of the tree in metres, i.e., let C.P. in centimetres represent the distance - BC in metres. Let a plumb line from L cut PN at M. Then in similar triangles ABC and MNL

$\angle CAB = \angle CLM = \angle LMN$

$$\frac{AB}{BC} = \frac{MN}{LN} = \frac{MN}{CP}$$

$$AB = \frac{BC \times MN}{CP}$$

As CP represents BC in metres, MN will represent the height of tree AB in metres.

17. INSTRUMENTS BASED ON TRIGONOMETRIC PRINCIPLES:

The instruments based on similar triangles are getting out of use since quick better and more reliable instruments, based on Trigonometric principles have come into use for measuring the height of trees. They are

- i) Simple clinometer
- ii) Brandis hypsometer
- iii) Wat-in's clinometer
- iv) Abney's level
- v) Topo Abney's level with Trailor Tape
- vi) Haga Altimeter, etc.

Recently Relaskop, Tele Relaskop, Barr and Stroud dendrometer, Blume-Leiss hypsometer, etc. are used. But they are comparatively costly and hence their use is limited.

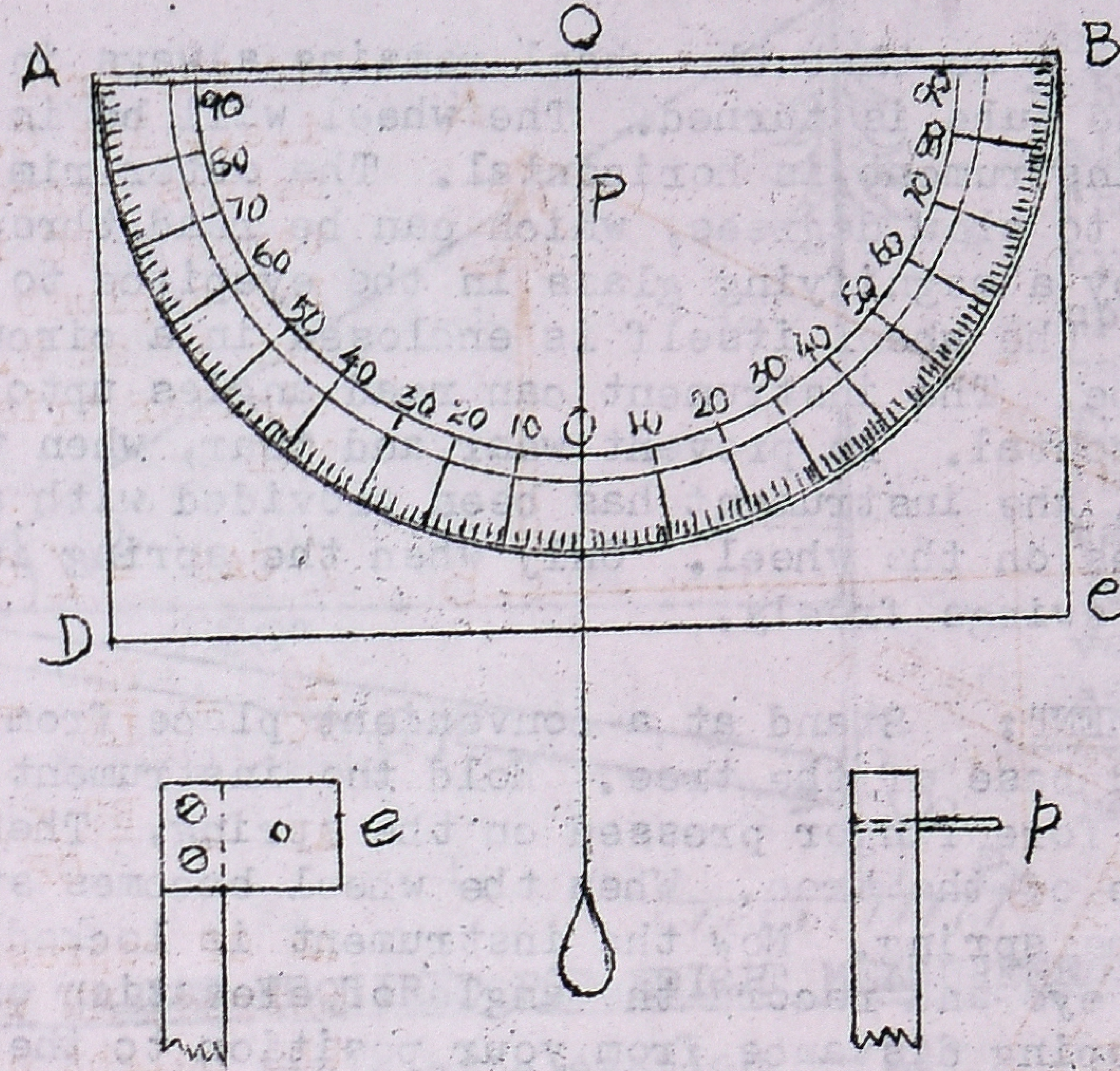
All these instruments are used to find the angle of elevation and depression to the top and base of the tree respectively. Then the horizontal distance from the observer to th: tree is measured. If the ground is sloping, horizontal distance is found out by multiplying the slope distance by the cosine value of the angle of slope. This horizontal distance is then multiplied with the Tangent value of angle of elevation and/or depression to get the height of the trees.

18. SIMPLE PLUMB LINE CLINOMETER:

This instrument may be constructed out of a sheet of stiff cardboard or thin flat wood, within short time.

a) Description: It consists of a rectangular sheet or card board or wood. ABCD of convenient size of 15cm x 9cm. On one side of the board, a paper containing semi-circular protractor is mounted. This semi-circle is graduated with 0° to 90° on either way with 0° mark at the centre. A plumb line P consisting a small weight suspended by a small string is fixed to the centre O of the circle. Fixing a small eye hole, on one side of the board and a projecting pin p on the other side as shown in the bottom of the figure will help for better accuracy

in taking the reading.

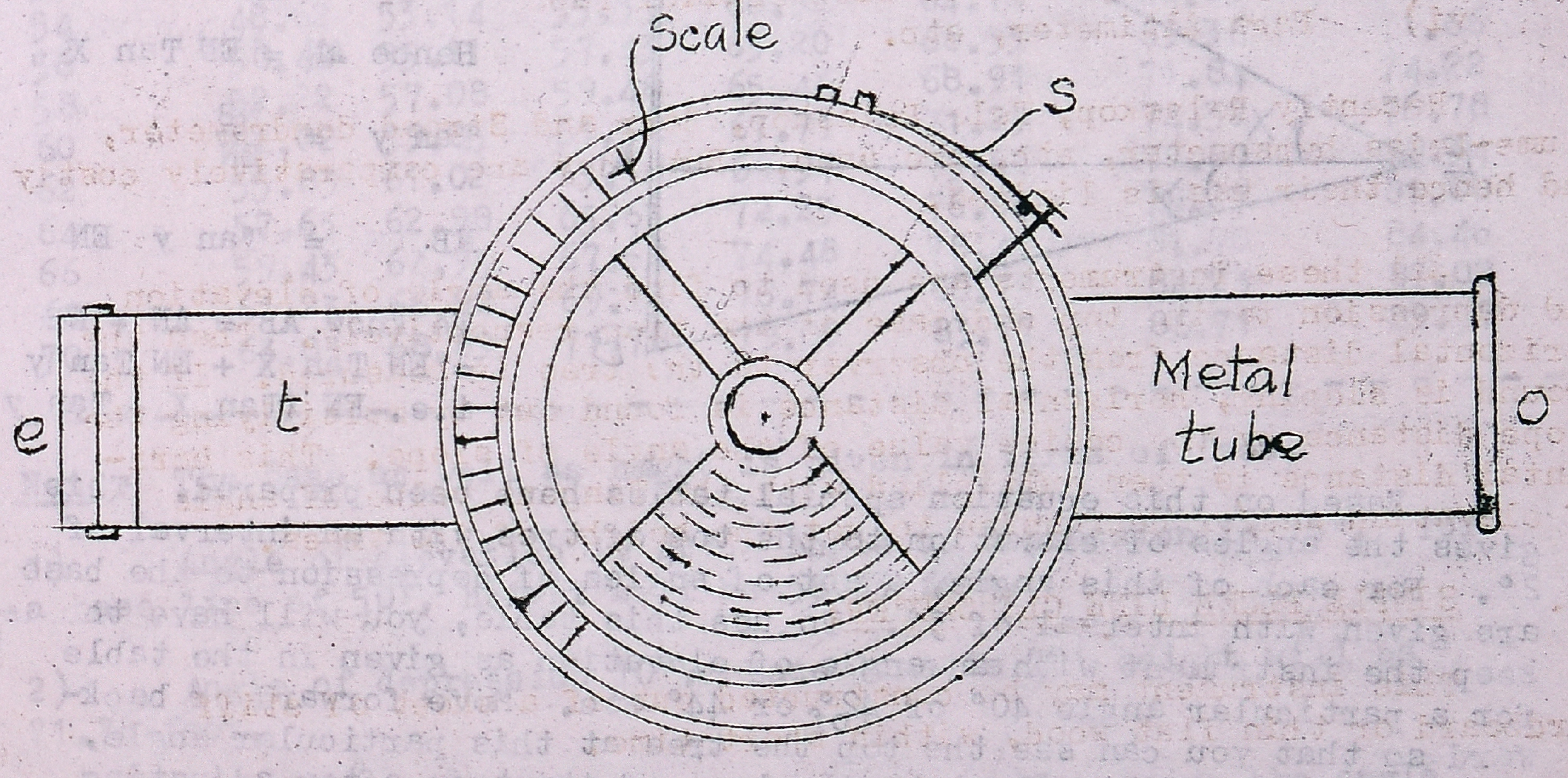


b) <u>How used</u>: Look along the straight edge AB to the top or base of the tree. The plumb line will indicate the angle of elevation or depression as the case may be.

c) <u>Advantages</u>: Cheap and easy to construct.

d) <u>Disadvantages</u>: It is difficult to keep the plumb line steady in wind.

19. <u>BRANDIS HYPSOMETER</u>

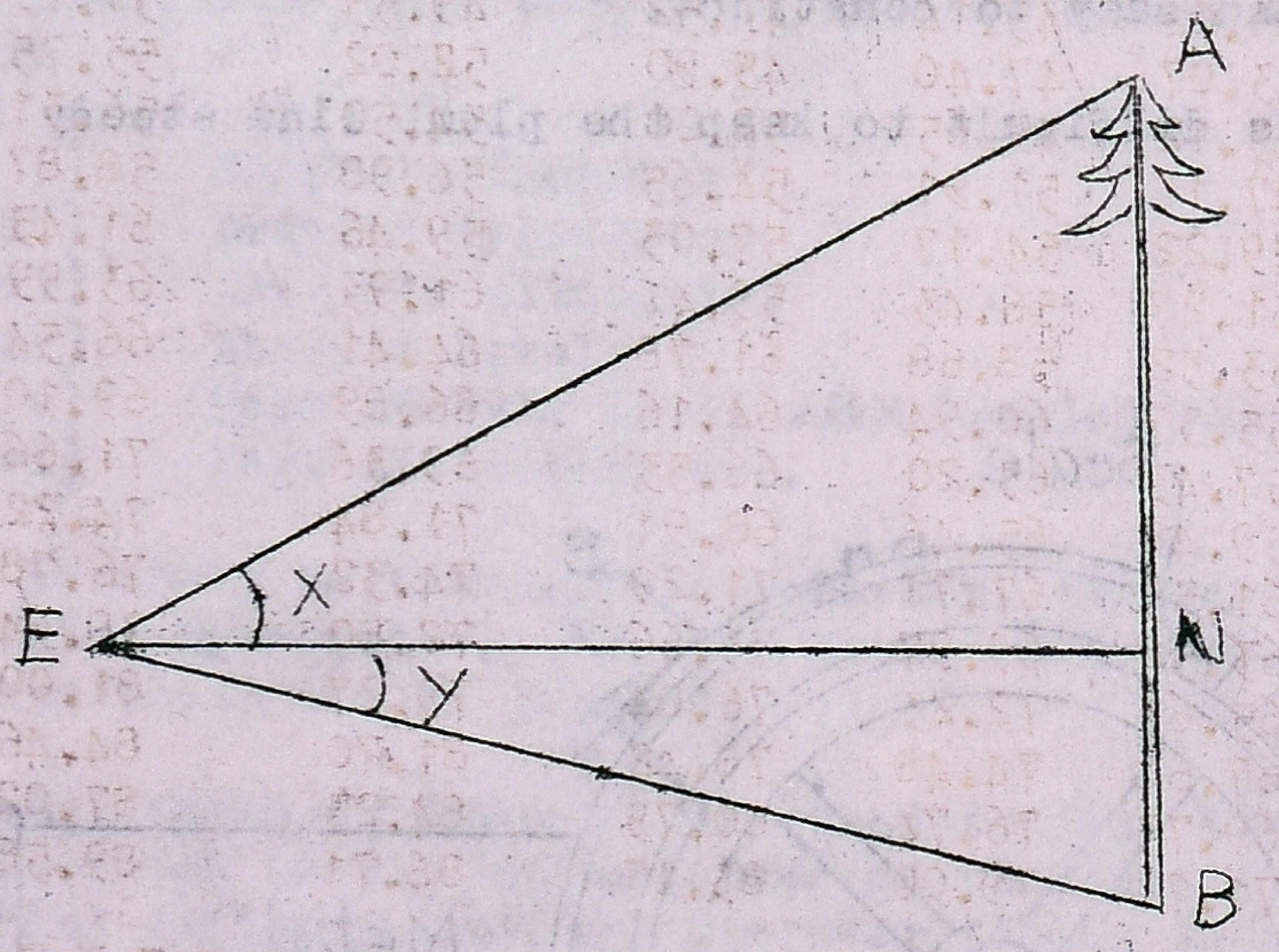


i) <u>Description</u>: This instrument consists of a hollow metal tube of about 14cm long and of rectangular cross section. It has a side tube <u>tt</u>, with an eye piece <u>o</u> at one end and cross wires <u>e</u> at the other end. The tube is attached to a pivoted wheel having

weight w on one side a so that the wheel remains always in the same position however the tube is turned. The wheel will be in zero position whenever the instrument is horizontal. The outer rim of the wheel has been graduated to show degrees, which can be read through an opening in the metal case by a magnifying glass in the eyepiece to give the angles in degrees. The wheel itself is enclosed in a circular case attached to the tube. The instrument can read angles upto 60° above and below the horizontal. To prevent wear and tear, when the instrument is not in use, the instrument has been provided with a retaining spring which presses on the wheel. Only when the spring is depressed, the weighted wheel swings freely.

ii) USING INSTRUMENT: Stand at a convenient place from where you can see the top and base of the tree. Hold the instrument in your left hand with the fore finger pressed on the spring. Then sight to the top or the base of the tree. When the wheel becomes steady, remove your finger from the spring. Now the instrument is locked. Remove the tube from your eye and record the angle of elevation or depression. Now measure the sloping distance from your position to the base of the tree. Then the height of the tree may be calculated from the formula you have studied.

iii) BRANDIS TABLE: The instrument has been provided with a table called " Brandis Table ". This will give the heights of trees directly.



Let AB be the tree and E the point of observer. Let the angle of elevation be x, and angle of depression be y.

In the figure,

$\tan X = \frac{AN}{EN}$

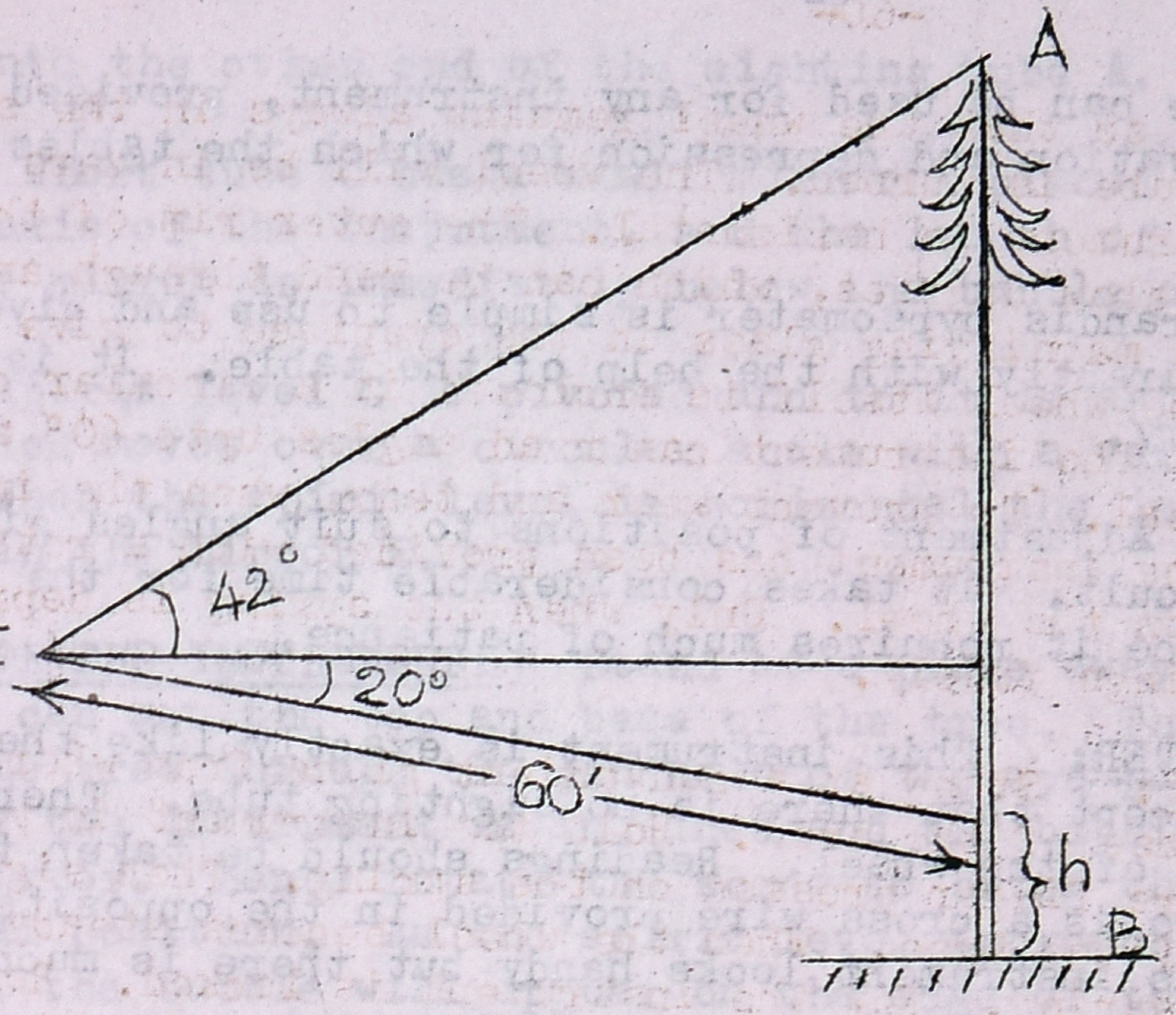
Hence $AN = EN \tan X$

$\tan y = \frac{NB}{EN}$

$NB = \tan y \cdot EN$

We know $AB = AN + NB$
$= EN \tan X + EN \tan y$
i.e. $EN (\tan X + \tan y)$.

Based on this equation special tables have been prepared. This gives the angles of elevation to the top of tree with an interval of 2°. For each of this angle, a set of angles of depression to the base are given with interval of 5°. To use this table, you will have to keep the instrument with an angle of elevation as given in the table for a particular angle 40° or 42° or 44° etc. Move forward or backward so that you can see the top of the tree at this particular angle. From the same position look to the base of the tree after adjusting to some angle of depression as given in the table - say 15°, 20° or 25° etc. You will see some point near the base of tree. Mark this point on the tree. Measure the height of the tree from the base upto



this point. Let this be h. Then measure the sloping distance along the ground. The height of the tree from the top upto the mark in the base can be found out from the table for the corresponding distance and angles of depression and elevation. h may be added to this height to get the total height of the tree.

SPECIMEN OF TABLES REQUIRED FOR HEIGHT MEASUREMENT OF TREE (ABRIDGED)

Angle of elevation — 42°

Base in ft.	0°	5°	10°	15°	20°	25°	30° Angle of depression
36	32.41	35.43	36.92	40.63	42.77	44.59	46.07
38	34.22	37.40	38.97	42.88	45.15	47.07	48.03
40	36.02	39.37	41.02	45.14	47.52	49.55	51.19
42	37.82	41.33	43.07	47.40	49.90	52.02	53.75
44	39.62	43.30	45.12	49.65	52.28	54.50	56.31
46	41.42	45.27	47.17	51.91	54.65	56.98	58.87
48	43.22	47.24	49.22	54.17	57.03	59.46	61.43
50	45.02	49.21	51.27	56.43	59.41	61.93	63.99
52	46.82	51.17	53.32	58.68	61.78	64.41	66.54
54	48.62	53.14	55.37	60.94	64.16	66.89	69.10
56	50.42	55.11	57.43	63.20	66.53	69.36	71.66
58	52.22	57.08	59.48	65.46	68.91	71.84	74.22
60	54.02	59.05	61.53	67.71	71.29	74.32	76.78
62	55.83	61.02	63.58	69.97	73.66	78.80	79.34
64	57.63	62.98	65.63	72.23	76.04	79.27	81.00
66	59.43	64.95	67.68	74.48	78.42	81.70	84.46
68	61.23	66.92	69.73	76.74	80.79	84.23	87.02
70	63.03	68.89	71.78	79.00	83.17	86.71	89.58

Note: The Base as well as height is given in terms of feet.

1) Angle of elevation is 42°. Angle of depression is 15°. For a base line of 50', height will be 56.43 feet.

2) Angle of depression 10°. Base line is 70' height will be 71.78 feet.

Specimen of the Table is given above. Supposing the angle of elevation is 42°, angle of depression is 20°, the sloping distance is 60 feet and h is five feet the height of the tree will be 71.29+5' = 76.29 feet.

Specimen of the table for an angle of elevation of 42° and for different sloping distance in intervals of 2 feet is shown above.

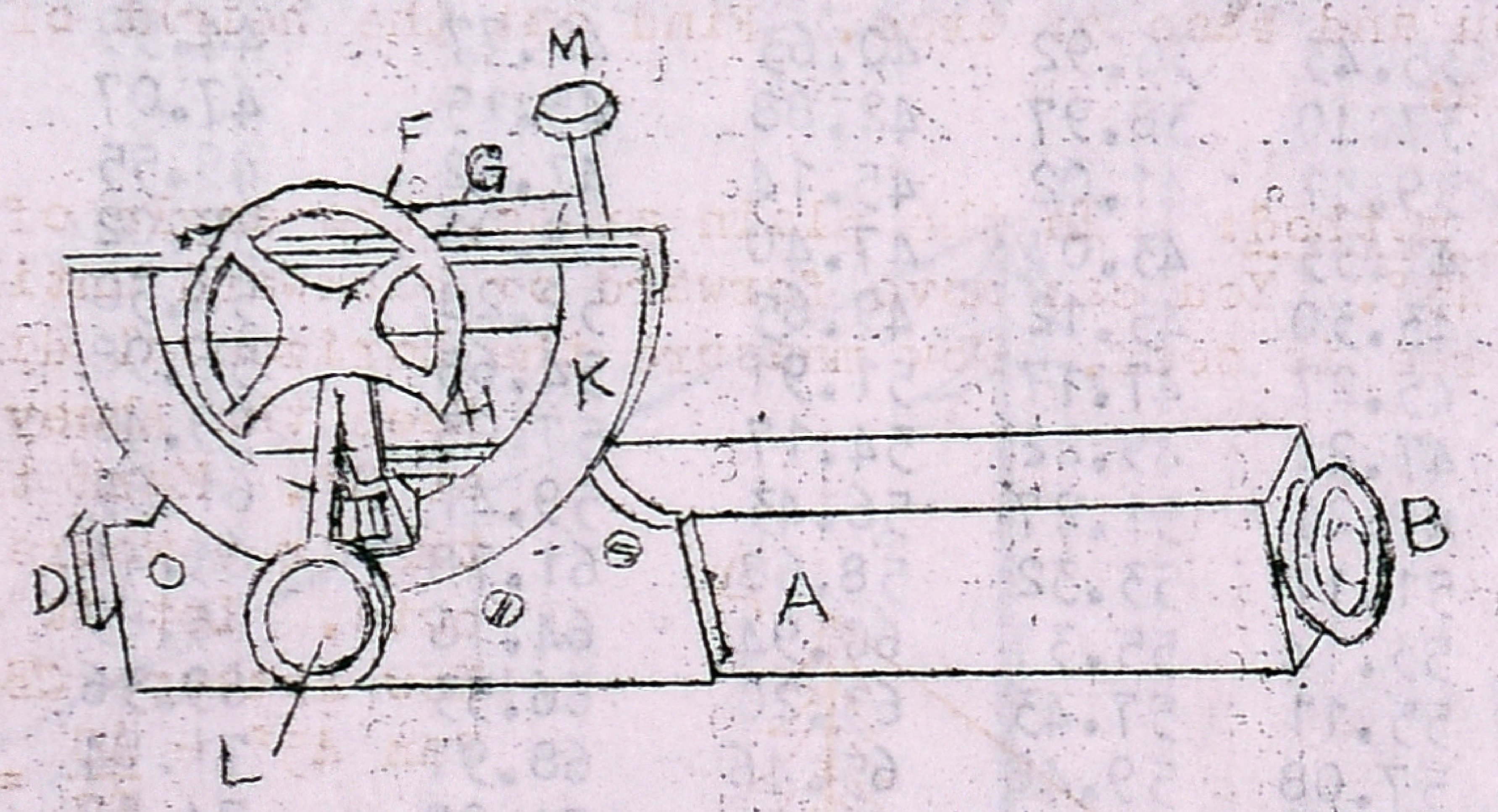
The Brandis table can be used for any instrument, provided we know the angle of elevation and depression for which the tables have been prepared.

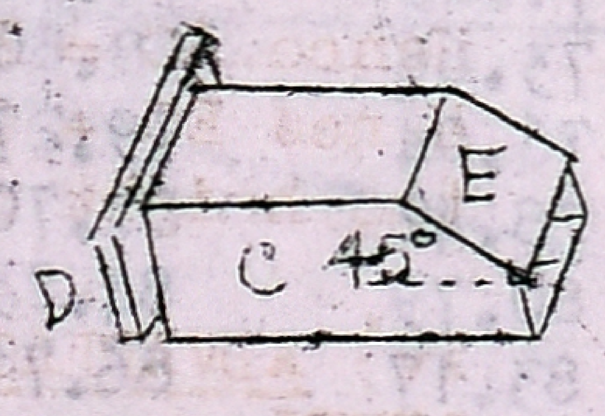
iv) Advantages: Brandis hypsometer is simple to use and gives the height of trees directly with the help of the table. It is very handy and easy to carry.

v) Disadvantages: Adjustment of positions to suit angles given in the table is difficult. It takes considerable time for the wheel to come to rest. Hence it requires much of patience.

20. WATKIN'S CLINOMETER: This instrument is exactly like the Brandis hypsometer except that there is no sighting tube. There is a pin hole on the rim of the wheel. Readings should be taken through this pin hole. There is a cross wire provided in the opposite end of the diameter. This instrument looks handy but there is much scope for error in this instrument.

21. ABNEY'S LEVEL: This is also known as Abney's clinometer. This is the most popular and invaluable instrument for the forest





officers. It was designed by Captain Abney. The principle underlying the construction of this instrument is that " if a ray of light strikes a plane mirror at an angle of 45°, then the ray will be reflected at right angle to its original direction."

This can be used for measuring angles of elevation and depression, slopes of the ground, tracing grade contour for alignment of a hill road and also as a hand level by setting the vernier to zero of graduation of scale.

i) CONSTRUCTION: It consists of a hollow square tube 'A' in one end of which is fitted an eye piece B, with a pin hole.

A short hollow tube, C, with its end half covered with a flange

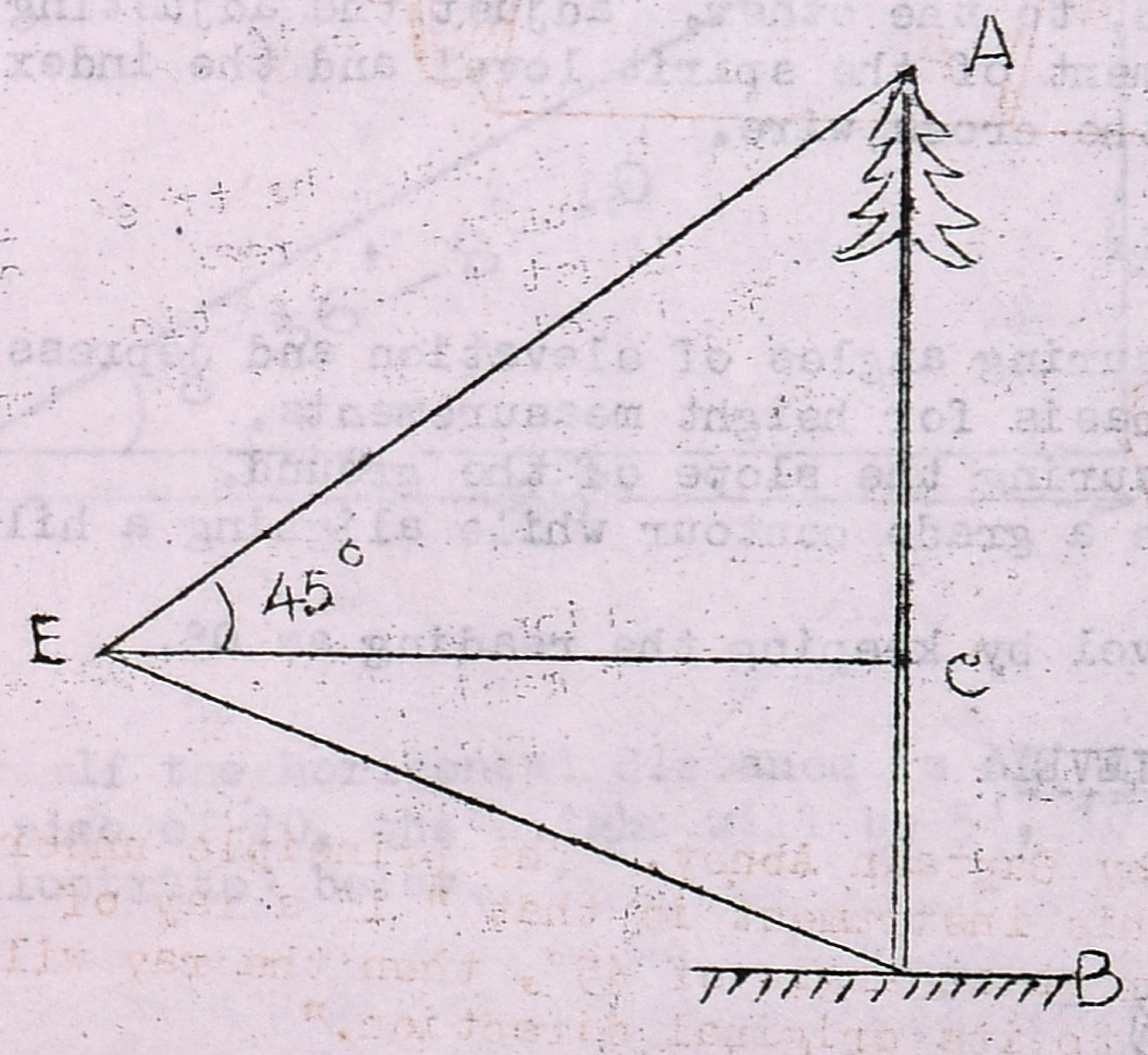
D fits into the other end of the sighting tube A.

This short tube C has a small mirror E placed at 45° to the longitudinal axis of the instrument, and the length of the tube is such that this mirror is immediately below the bubble of the spirit level F.

The spirit level G is pivoted and to it is attached an indicating arm H which moves over a circular scale with a vernier and magnifying glass. When the spirit level is horizontal the image of the bubble is seen in the mirror E.

ii) USE OF THE INSTRUMENT: Stand at a place away from the tree so that you can see the top and base of the tree. Then sight at the top of the tree through the pin hole of the eye piece after pulling it out. Now the instrument is inclined and the bubble will not be seen in the mirror. Hence rotate the screw to bring the spirit level in horizontal position. As the spirit level approaches the horizontal position, the bubble will appear on the edge of the mirror. Move the spirit level slowly to the position when bubble image is bisected by the line of horizontal wire on the mirror and in the other half the tree top is seen touching the horizontal wire. At this position, read the angle of elevation to the top of the tree on the circular arc (with the help of vernier and magnifying lens if necessary). Similarly read the angle of depression to the base. Then measure the distance between you and base of tree. Find out the height of the tree using the formula:

iii) Practical method: In the plain areas, the angle of elevation may be fixed at 45°. You can move forward or backward until the top portion of the tree is seen. Now measure the horizontal distance EC.



Keep the Abney's reading at 0°. Mark the place on the tree where this 0° cuts. Let it cut at C. Now measure CB.

$\text{Tan } 45° = \frac{AC}{EC} = 1$

Hence AC = Ec; (Tan 45=1)
Hence EC + CB will give the height of the tree.

iv) ADVANTAGES OF ABNEY'S LEVEL:

a) It is light, compact and handy.
b) It is the most accurate instrument used for height measurement. Angles can be read correct to 10' with the help of vernier attached.
c) Measurements can be taken quickly.
d) We can measure even in windy weather.

v) DISADVANTAGES: Once it gets out of adjustment it cannot be easily set right. It is costlier than other height measuring instruments.

vi) TESTING THE ABNEY'S LEVEL: Abney's level can be tested with following methods:

i) Fix up two rods about a chain apart. Set the tops of these rods perfectly level with the help of telescopic levels. Take the reading from the top of one rod to the top of other. This should be zero. If not, set up the instrument at zero and adjust the adjusting screws and see that the bubble is brought central. Thus it can be adjusted.

ii) If Telescopic level is not available, the instrument may be tested by reciprocal observations. Take 2 Ranging Rods A & B and fix horizontal vanes at convenient height - say 1.3 metres on each of them. Fix these rods on sloping grounds. Let A be on the lower slope and B be at the higher slope. Take the reading from A to B. Let it show an angle of elevation of 10°40'. Take similar reading from B to A. If it shows 10°40' as angle of depression, the instrument is in adjustment. If not it is not in adjustment. Let it show 10°20'. The true value of the angle of inclination will be

$$\frac{10°40' + 10°20'}{2} = 10°30'$$

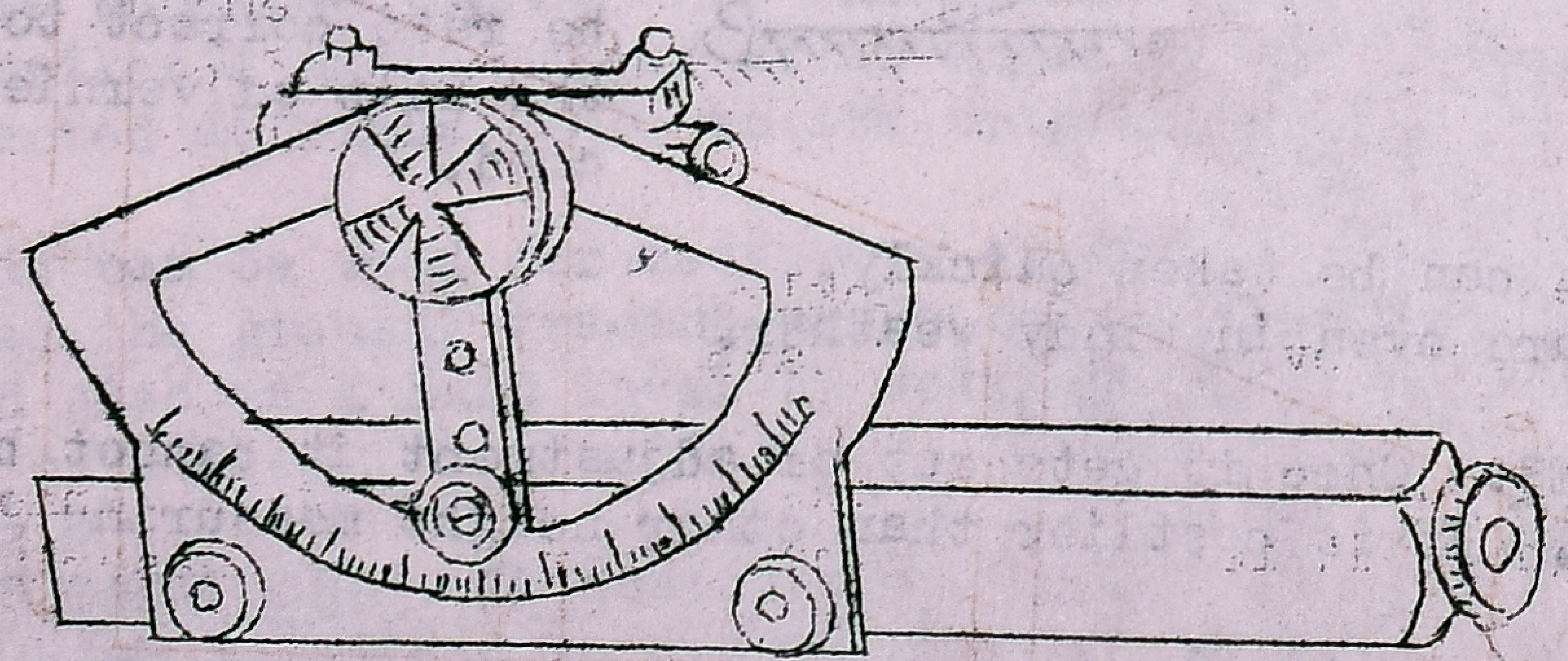
The index error will be $\frac{10°40' - 10°20'}{2} = 10'$

ii) Adjusting the Abney's level: In the above case the true value of inclination is 10°30'. Hence set up the instrument to read 10°30' and sighting from either rod, to the other, adjust the adjusting screws controlling the movement of the spirit level and the index arm until the bubble is cut by the cross wire.

vii) USES OF ABNEY'S LEVEL:

i. Used for measuring angles of elevation and depression. This is the basis for height measurements.
ii. Used for measuring the slope of the ground.
iii. Used to trace a grade contour while aligning a hill road.
iv. Used as a level by keeping the reading as 0°.

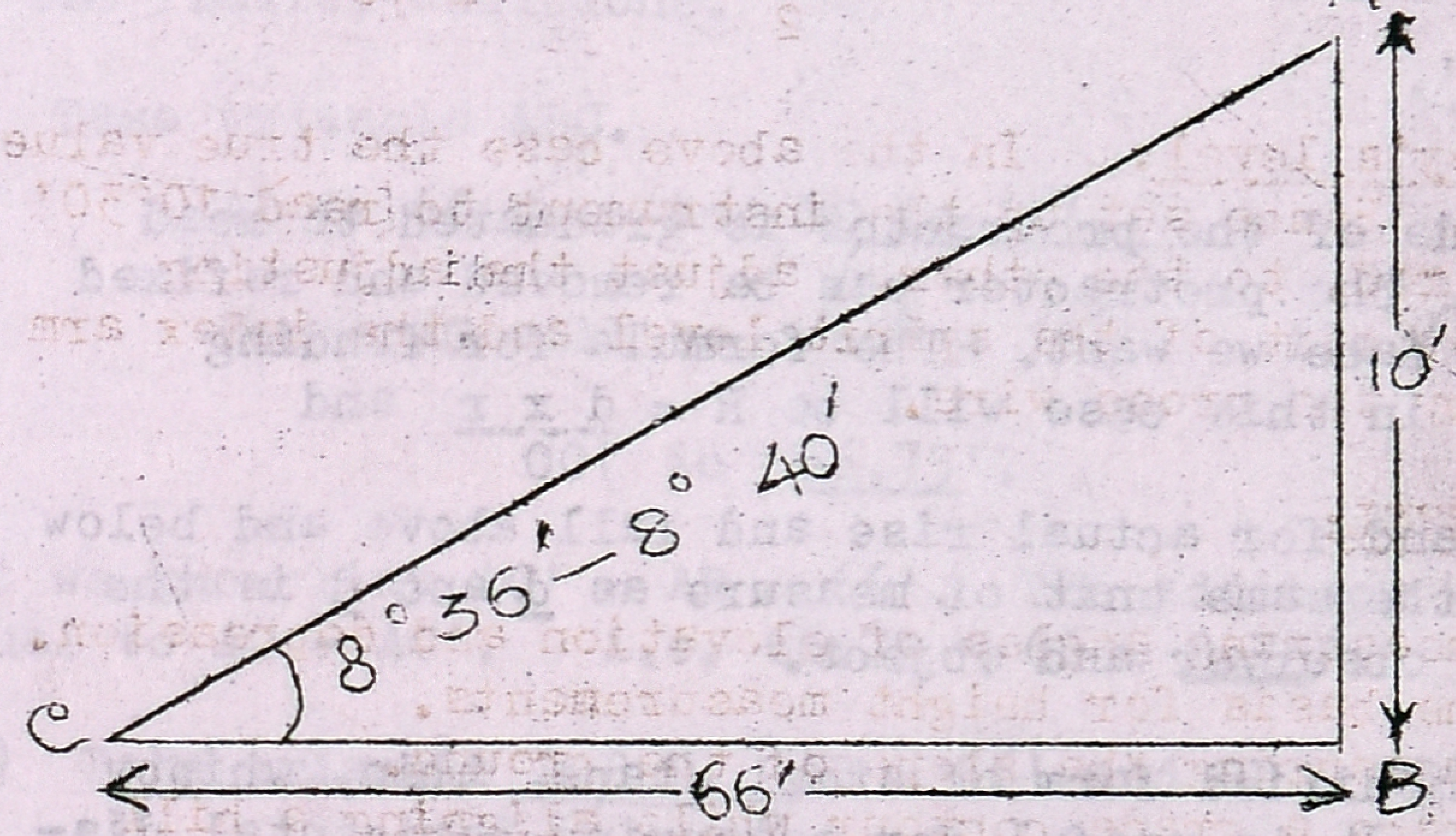
22. TOPOGRAPHIC ABNEY'S LEVEL:



22.1 This instrument is also known as Improved or Modified Abney level. Ordinary Abney's level, though light and handy and the best levelling instrument, reads angles of elevation and depression alone. It is necesssary to use trigonometrical tables to find out the heights of objects. But Topo Abney, which was designed by the American Military Authorities, dispenses with the use of trigonometrical tables, when used along with a Trailer tape. Hence it serves the simplest and the most suitable instrument.

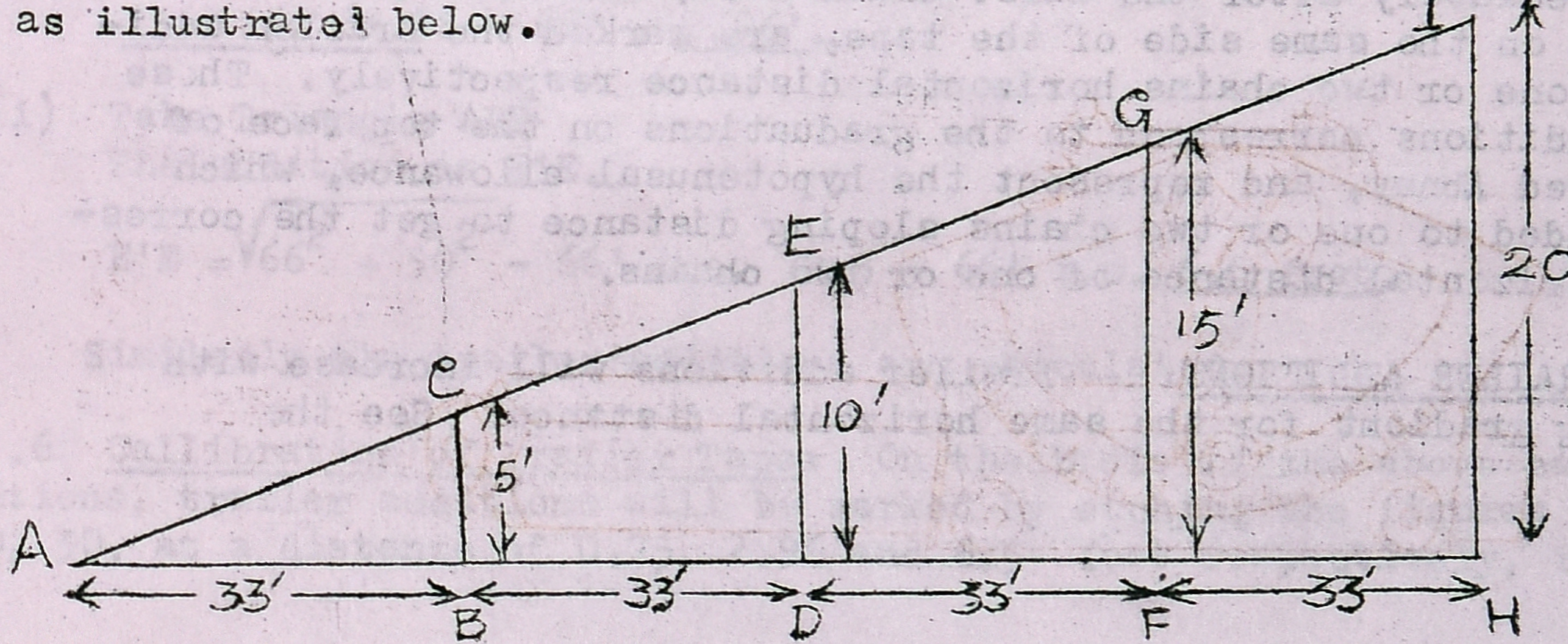
22.2 Description: This is similar to the Abney's level except for minor differences. The graduated arc does not give degrees but gives rise or fall in feet per Gunter's chain (66') horizontal distance. The protractor of this instrument is graduated on both sides. One side gives the rise and fall per chain horizontal distance and the other side gives the percentage rise and fall (i.e., vertical rise or fall in feet for 100 feet horizontal distance).

22.3 How Topo Abney is useful: The protractor of Topo Abney reads the rise or fall of the sighted object for every 66 feet of horizontal distance. It does not give angles. In other words, it reads the tangent values of the angles of elevation or depression by means of a fraction with a constant denominator i.e. 66'.



Suppose the instrument, when sighted to an object reads a rise of 10, it means that the height of the object above the horizontal has to be calculated at 10 feet for every 66 feet of horizontal distance between the observer and the object. This means the Tan value of angle ACB is 10/66 or 0.151515, which is the value of 8°36' to 8°40'. Hence for an angle of 8°36', this instrument has directly given the height - provided the horizontal distance is 66 feet.

If the horizontal distance is 33' or 66' or 99' or 132' for the same rise of 10, the height will be 5', 10', 15' and 20' respectively, as illustrated below.



The formula for finding out the actual rise or fall will be

$R = \frac{d \times r}{66}$ and $F = \frac{d \times f}{66}$ where R = Actual Rise and r the reading of instrument; F = Actual fall and f the reading of instrument, and d is the horizontal distance between object and observer.

In the figure,

if AB is 33', BC is 5'
if AD is 66', DE is 10'
if AF is 99' GF is 15'
if AH is 132', IH is 20'.

Note: Same will be the case for depression also.

By formula:

$R = \frac{d \times r}{66}$ Let us find GF.

The distance AF is 99'. Rise as per instrument is 10.

Hence $R = \frac{99 \times 10}{66}$ i.e. 15'.

Let us find IH.

Distance AH is 132'.

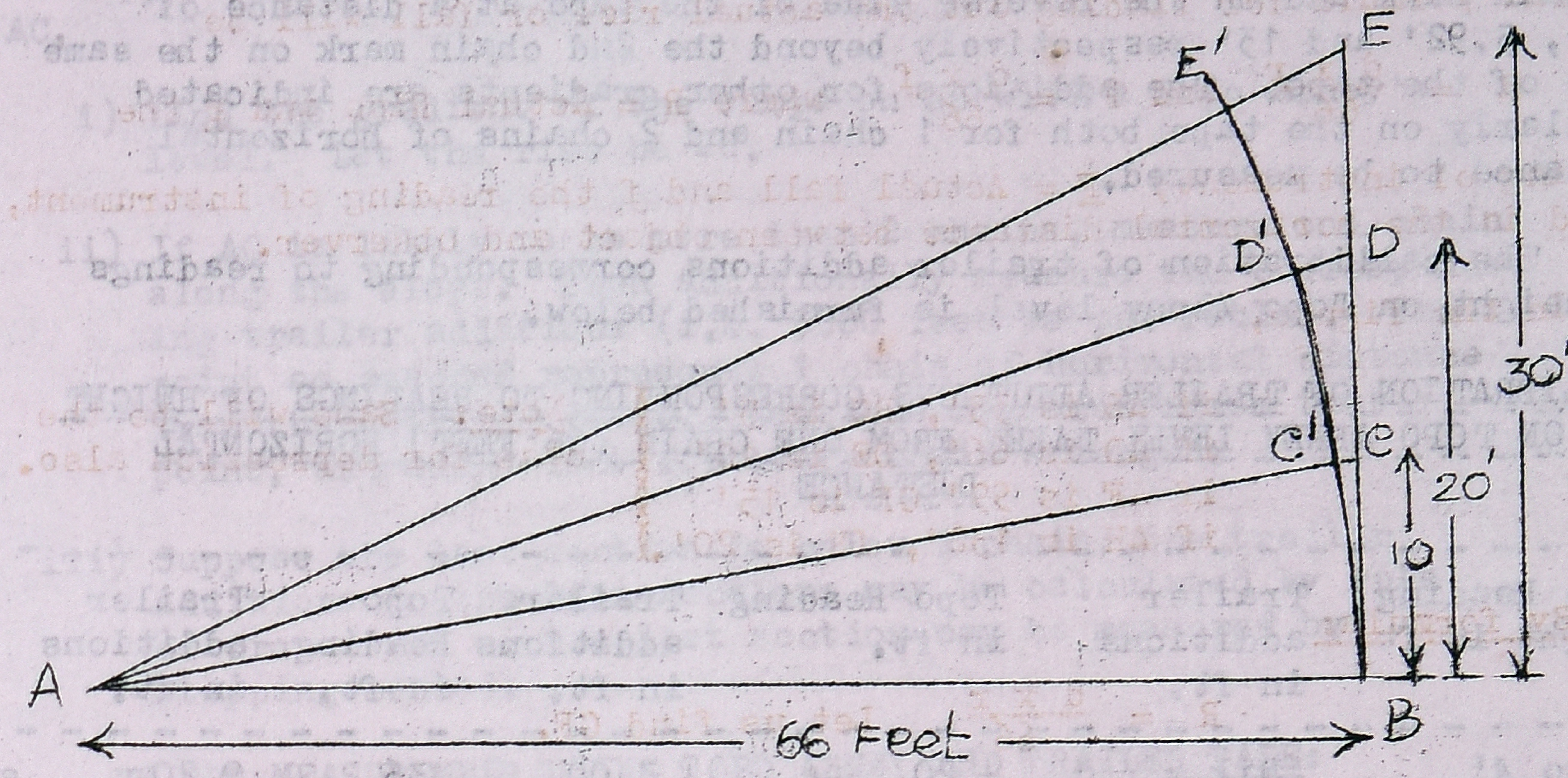
$R = \frac{132 \times 10}{66} = 20'$.

Rise or fall: Other side of the protractor is graduated to read percentage of rise or fall. The protractor can be removed and refixed so that we can use whatever face we want. The formula for finding out the actual rise or fall in this case will be $R = \frac{d \times r}{100}$ and $F = \frac{d \times f}{100}$ where r and f stand for actual rise and fall above and below the horizontal measured in the same unit of measure as d and d is the horizontal distance between observer and object.

22.4 TRAILER TAPE is a modified form of steel tape, thin, whippy and narrow in construction. It is useful for measuring horizontal distance on sloping ground without any calculation. It consists of a steel tape 2 chains (Gunter's chain of 66 feet) in length, with a trailer half a chain long. On one side the tape is graduated to read links upto 2 chains length. On the reverse side of the second chain length immediately after the first chain mark, and after the second chain mark on the same side of the tape, are marked the Trailer additions for one or two chains horizontal distance respectively. These trailer additions correspond to the graduations on the top face of the Improved Abney, and represent the hypotenusal allowance, which must be added to one or two chains sloping distance to get the corresponding horizontal distance of one or two chains.

22.5 TRAILER ADDITIONS: Trailer additions will increase with increasing gradient for the same horizontal distance. See the

figure below. AB is the horizontal distance. Let BC be 10', CD be 10'



and DE be 10'. Hence BC is 10', BD is 20' and BE is 30'.

Let AB be of 66'.

With A as centre and AB as radius draw an arc. It will cut AC at C', AD at D' and AE at E'. In the above figure, C'C, D'D and E'E will be the Trailer additions.

i) Take triangle ABC.

AB is 66 feet and BC is 10'.

Hence AC will be $\sqrt{66^2 + 10^2}$ i.e. $\sqrt{4356 + 100}$

ie 66.75'.

But we know that AC' = AB = 66'. The addition will be C'C which is equal to AC - AC'. i.e. 66.75 - 66 = 0.75'.

ii) Take triangle A B D. AB = 66' and BD = 20'.

Hence AD $= \sqrt{66^2 + 20^2}$

i.e. $\sqrt{4356 + 400}$ = 68.96 feet.

We know that AD' = AB = 66 feet.

The addition will be D'D, which is equal to AD - AD'.

i.e. 68.96 - 66' = 2.96'.

iii) Take Triangle ABE

The addition is E'E.

E'E $= \sqrt{66^2 + 30^2} - 66'$ i.e. 72.5 - 66' i.e. 6.5 feet.

Similarly the trailer additions are calculated.

22.6 Callibration of Trailer Tape: On the basis of the above calculations, trailer additions will be marked by etching the figures 10, 20, 30, at a distance of 0.75, 2.96 and 6.5 feet respectively, from

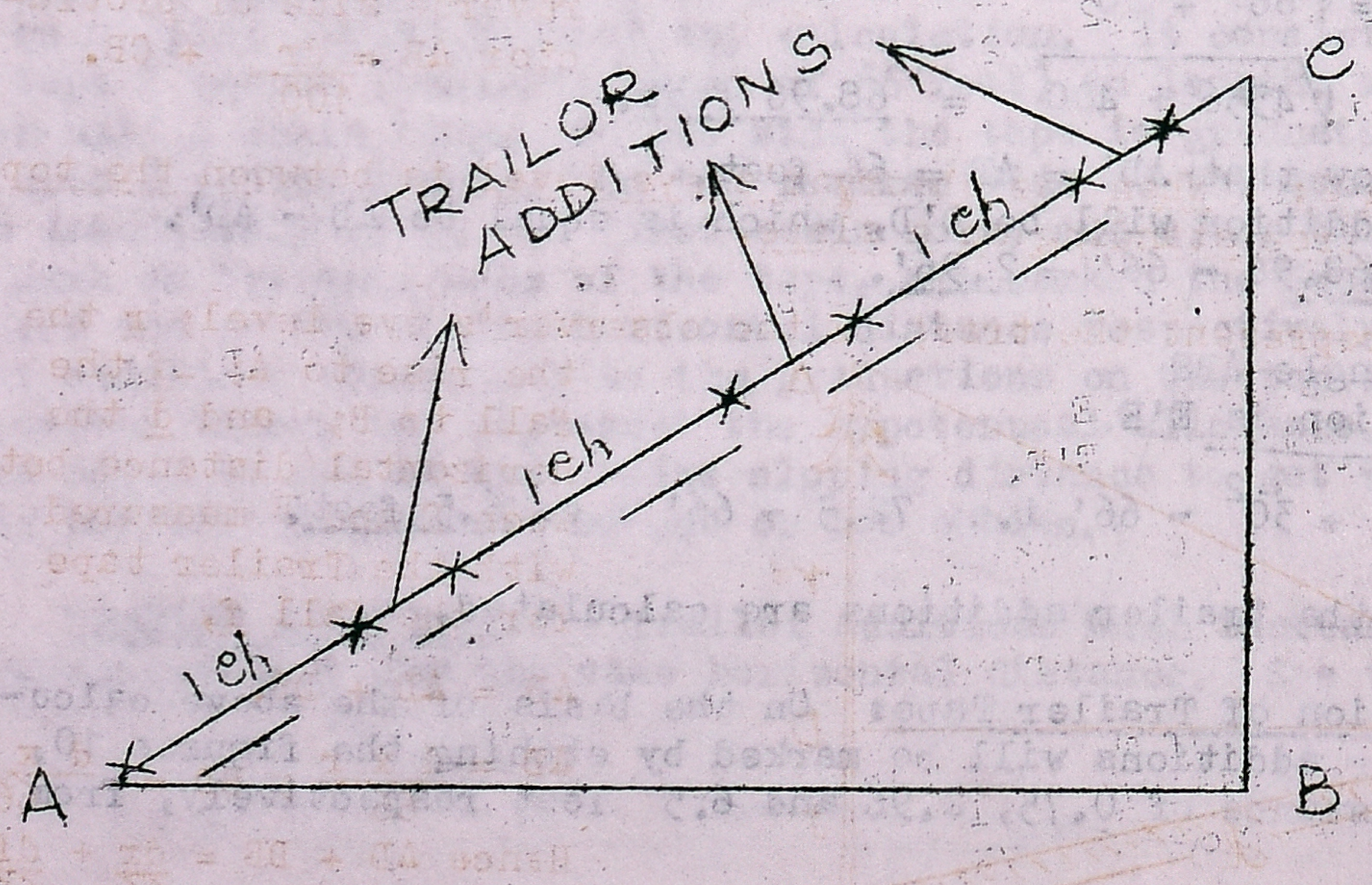
1 chain mark and on the reverse side of the tape at a distance of 1.5', 5.92' and 13' respectively beyond the 2nd chain mark on the same side of the tape. The additions for other gradients are indicated similarly on the tape both for 1 chain and 2 chains of horizontal distance to be measured.

The callibration of trailer additions corresponding to readings of height on Topo Abney level is furnished below.

CALLIBRATION OF TRAILER ADDITIONS CORRESPONDING TO READINGS OF HEIGHT ON TOPO ABNEY LEVEL TAKEN FROM ONE CHAIN (66 FEET) HORIZONTAL DISTANCE

Topo Reading height in ft.	Trailer additions in ft.	Topo Reading in ft.	Trailor additions in ft.	Topo Reading in ft.	Trailer additions in ft.
1' to 4'	Nil	20	3.00	36	9.20
5	0.21	21	3.27	37	10.00
6	0.30	22	3.56	38	10.66
7	0.38	23	3.90	39	11.20
8	0.50	24	4.23	40	11.50
9	0.60	25	4.60	41	12.00
10	0.76	26	4.95	42	12.50
11	0.90	27	5.30	43	13.20
12	1.10	28	5.70	44	13.60
13	1.26	29	6.10	45	14.00
14	1.46	30	6.50	46	14.60
15	1.60	31	7.00	47	15.20
16	1.79	32	7.50	48	15.80
17	2.16	33	7.80	49	16.20
18	2.40	34	8.25	50	16.80
19	2.68	35	8.80		

22.7 **HOW TRAILER TAPE IS USED:**



Supposing it is required to measure the horizontal distance for AC,

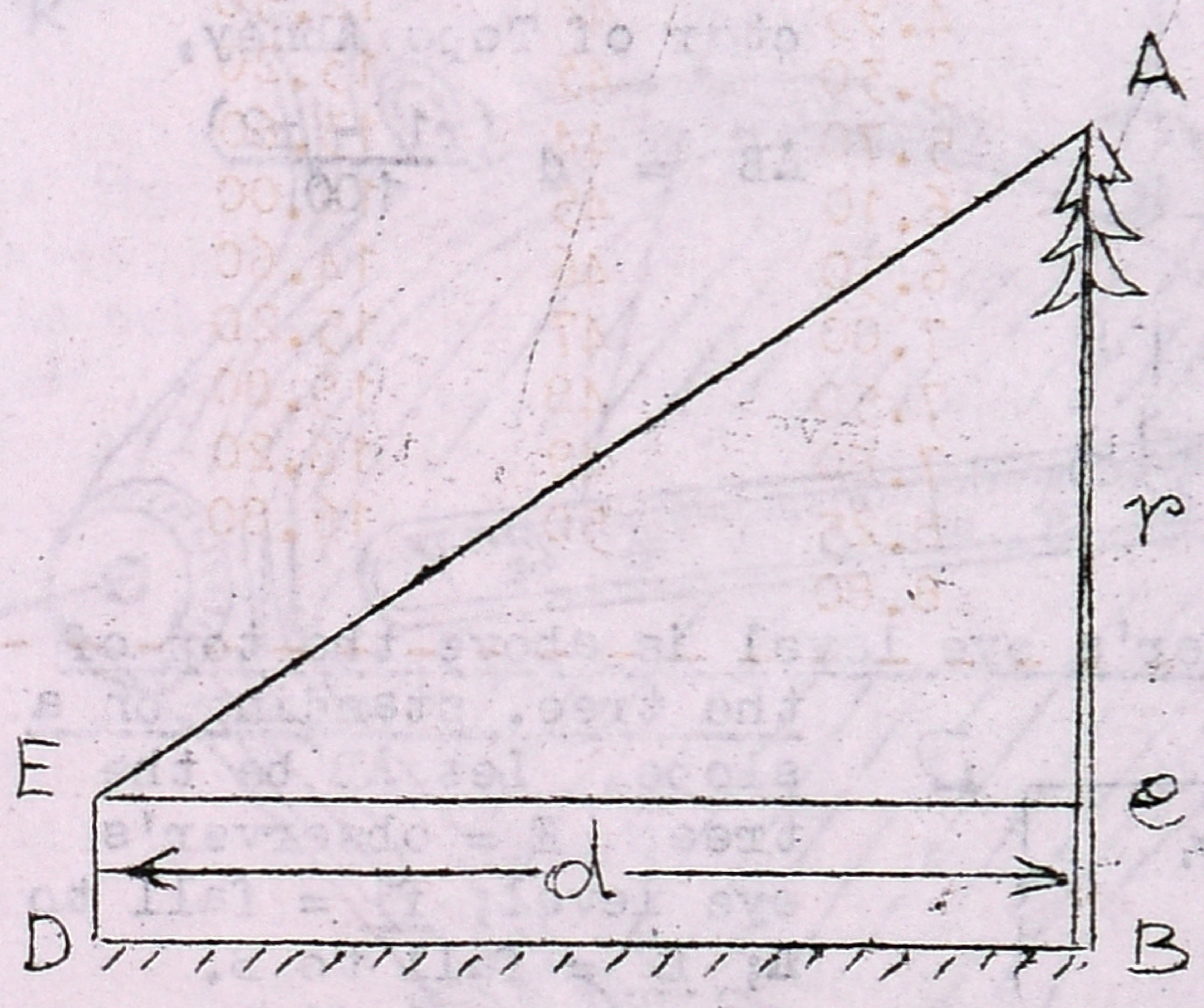
i) find the gradient of the slope on AC with a Topo Abney's level. Let the rise be 20.

ii) If AC is likely to be more than 2 chains, measure one chain along the slope. Then additionally measure the corresponding trailer additions (i.e. 3.00 feet as per Table). The point so reached represents 1 chain of horizontal distance from the starting point. Continue measuring from that point, and add 3 feet for every chain's length.

iii) Suppose the last section is below 1 chain, the trailer additions to the last sections may be calculated by rule of proportion or the last section may be measured by stepping method.

22.8 HEIGHT MEASUREMENT USING TOPO ABNEY AND TRAILER TAPE:

i) Position 1: When the tree is on level ground



a) Let AB be the tree on the level ground. Let E be the eye level of the observer and d be the horizontal distance and r be the rise according to the Topo Abney's level, when sighted to A from E.

AB = AC + CB.

But $AC = \frac{d \times r}{66}$

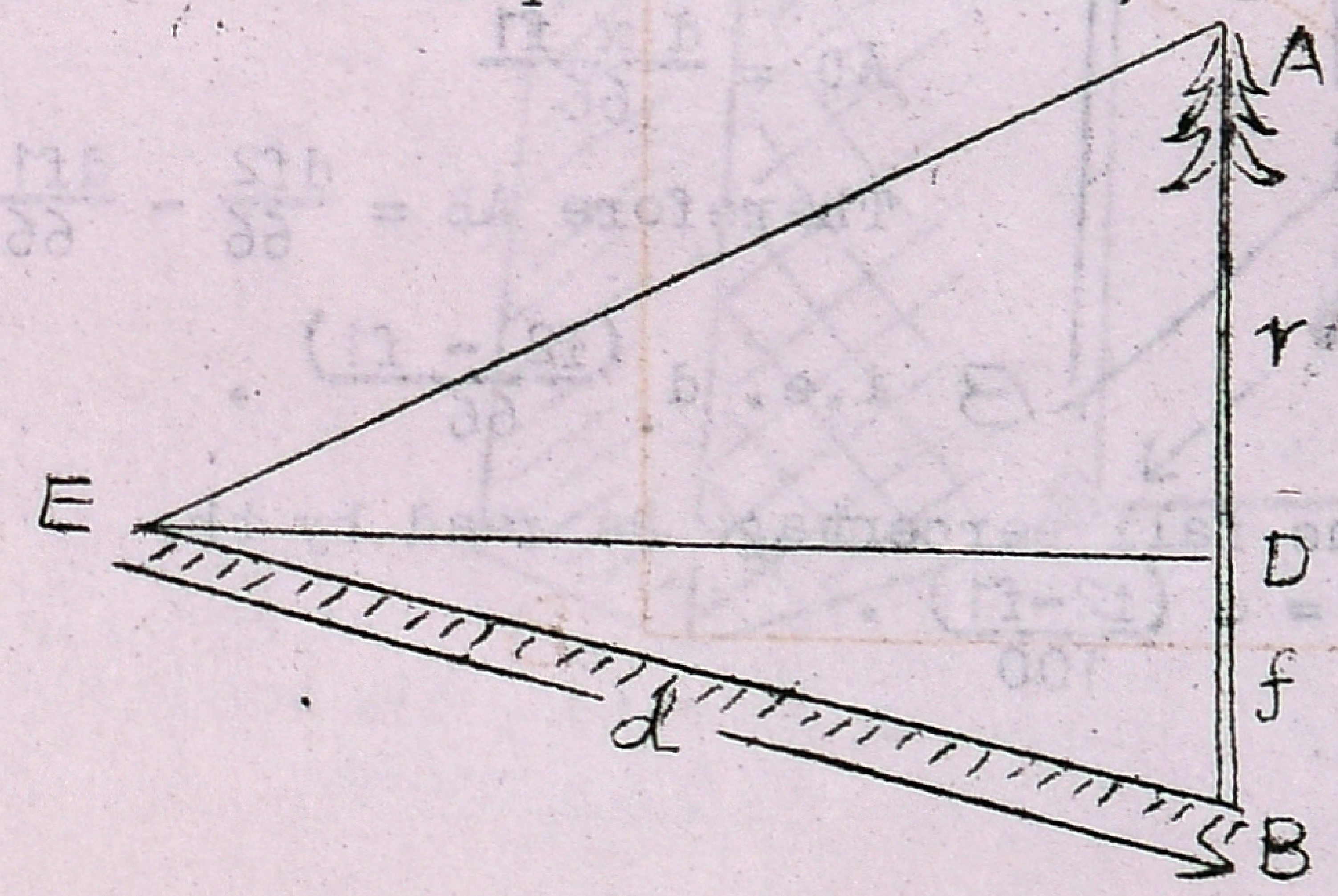
Therefore $AB = \frac{d \times r}{66} + BC$

BC can always be measured.

b) If r' represents the rise as read in the reverse side of protractor $AB = \frac{dr}{100} + CB$.

ii) Position 2: When the observer's eye level is between the top and base of the tree standing on a slope.

a) Let AB represent the tree; E the observer's eye level; r the rise to A; -f the fall to B; and d the horizontal distance between E and B measured with the Trailer tape for the fall f,



AB = AD + DB.

$AD = \frac{d \times r}{66}$; $BD = \frac{d \times f}{66}$

Hence $AD + DB = \frac{dr}{66} + \frac{df}{66}$

i.e. $d\frac{(r + f)}{66}$.

b) If r' and f' represent the rise and fall as read on the reverse side of the protractor, $AB = d\ \frac{(r' + f')}{100}$.

iii) Position 3: When the observer's eye level is below the base of the tree, standing on a slope:

a) Let AB represent the tree; E the eye level of observer; r^1, the rise to the top of tree A; r^2 the rise to the base of the tree B1.

d: the horizontal distance between E and B measured with Trailer Tape for the rise of r^2.

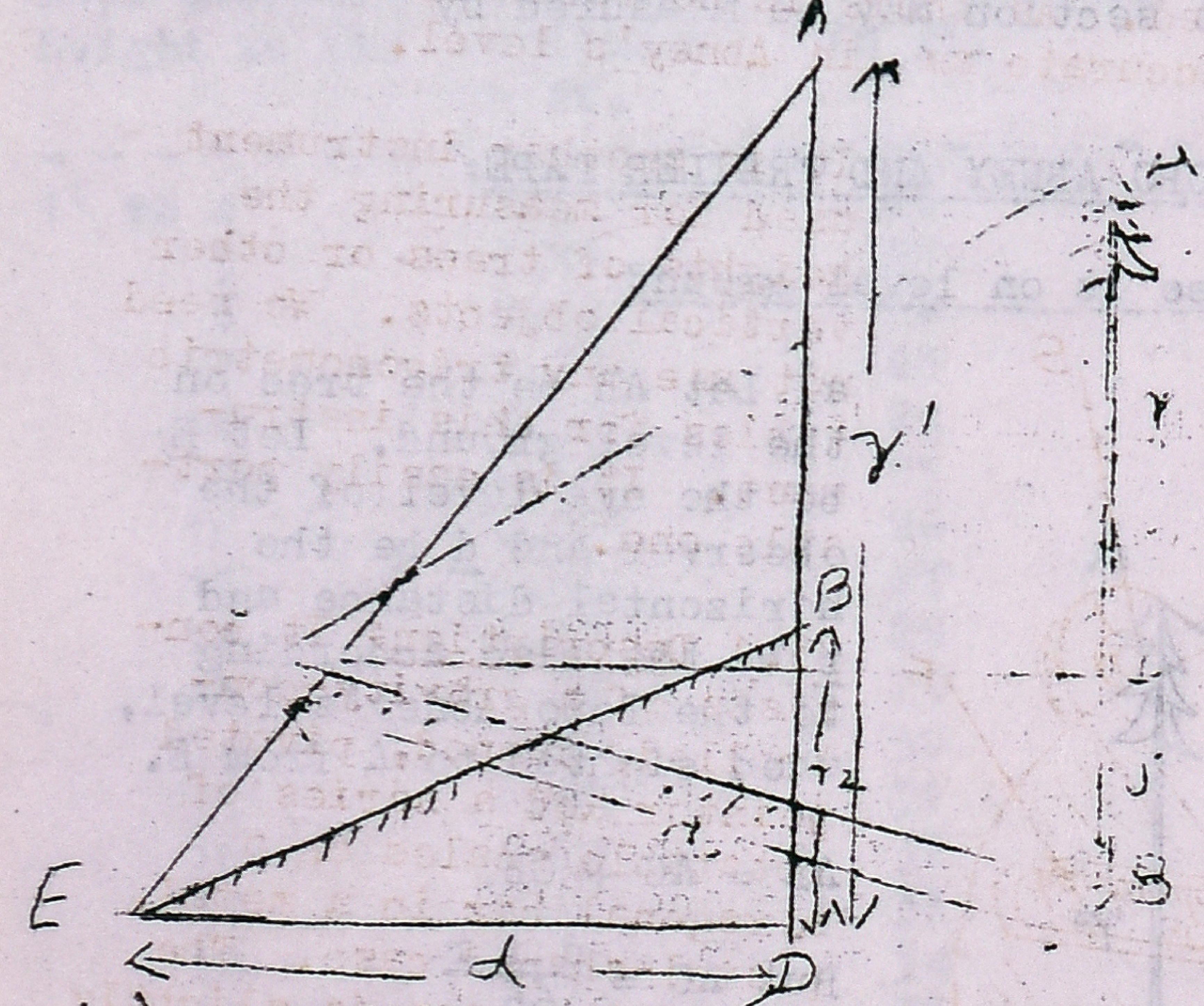
Then AB = AD - BD; $AD = \frac{d \times r1}{66}$ $BD = \frac{d \times r2}{66}$

$$AD - BD = \frac{dr1}{66} - \frac{dr2}{66}$$

$$\text{i.e. } d\ \frac{(r1 - r2)}{66}$$

b) When r1 and r2 represent the rise to A and rise to B respectively as read by the reverse side of the protractor of Topo Abney,

$$AB = d\ \frac{(r1 - r2)}{100}$$



iv) Position 4: When the observer's eye level is above the top of the tree, standing on a slope. Let AB be the tree; E = observer's eye level; f1 = fall to A; f2 = fall to B. d horizontal distance between E and B with the Trailer Tape for the fall of f2.

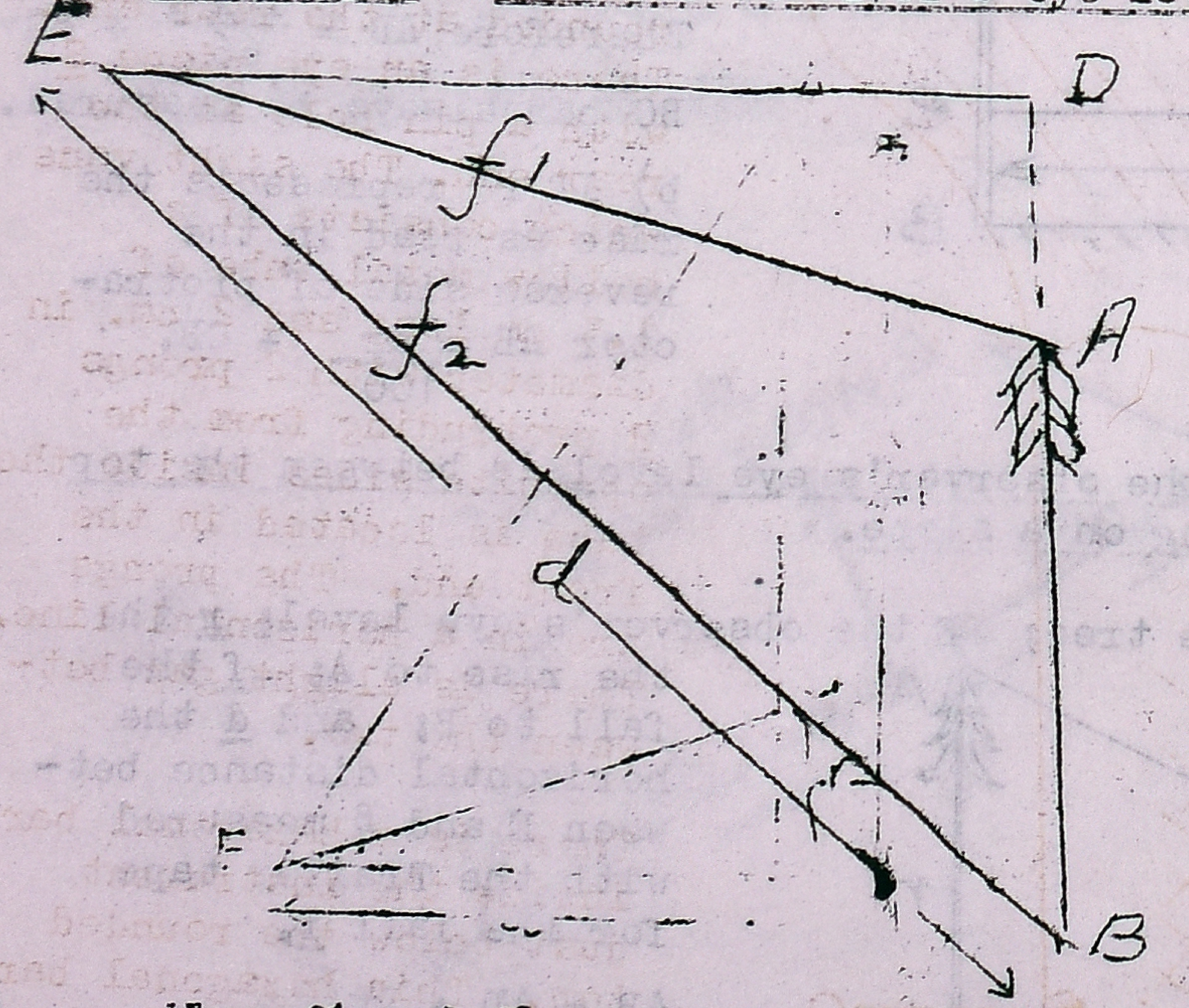
Then AB = DB - DA;

$$DB = \frac{d \times f2}{66};$$

$$AD = \frac{d \times f1}{66}$$

$$\text{Therefore } AB = \frac{df2}{66} - \frac{df1}{66}$$

$$\text{i.e. } d\ \frac{(f2 - f1)}{66}.$$



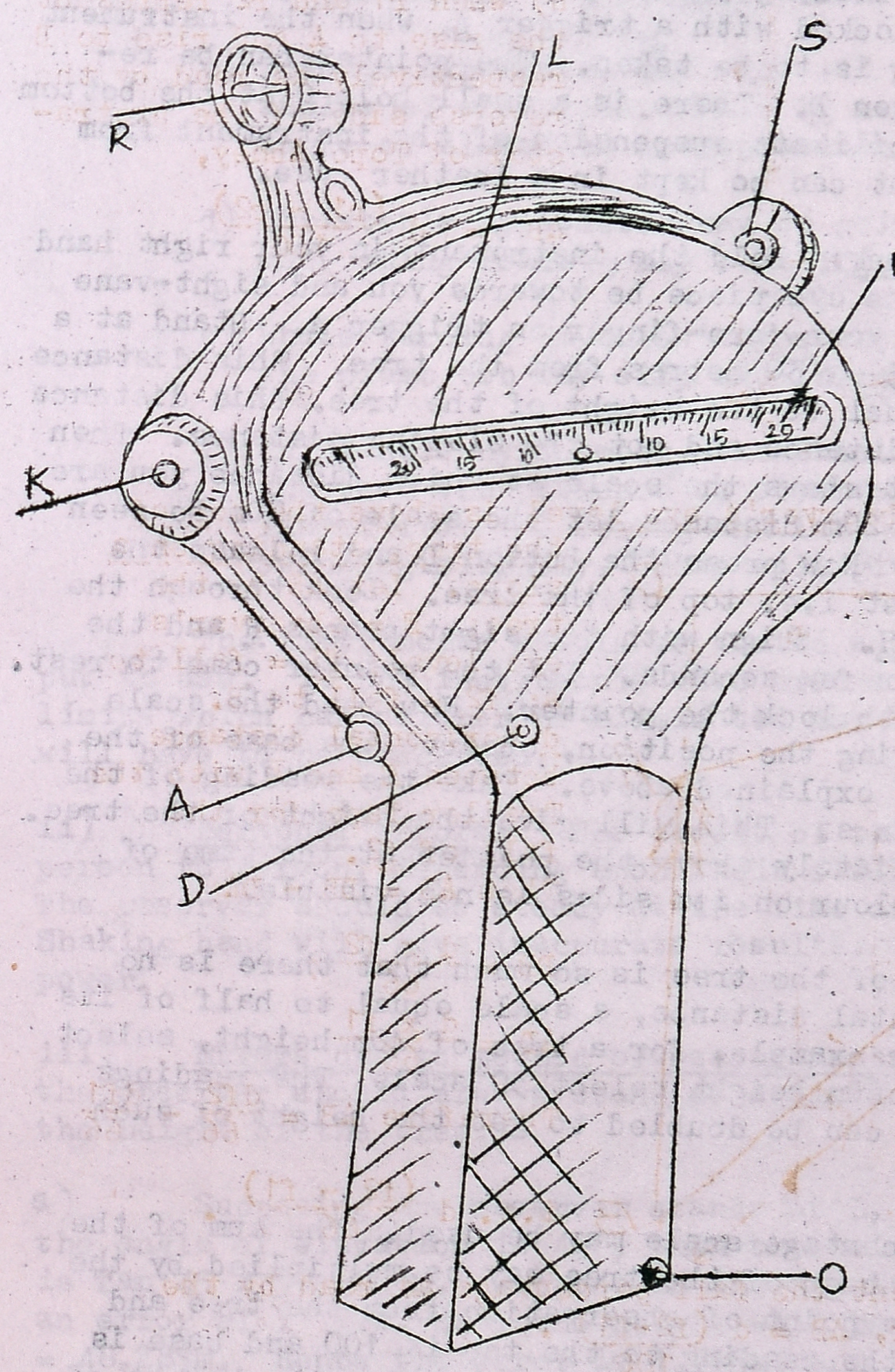
b) When f1 and f2 represent the fall percentage as read by the reverse side of the protractor, $AB = d\ \frac{(f2-f1)}{100}$.

22.9 Difference between Abney's level and Topo Abney's level:

Abney's level is smaller in size, with small protractor, graduated only in one side. The protractor cannot be removed. It can read the angle of elevation and depression. It can read the gradients of 1 in 1 to 1 in 10. There is a vernier attached and hence the angles can be read upto 10 minutes. Heights of trees can be measured with ordinary tapes. Height measurements can be calculated with mathematical calculations. Abney's level can be used for contour survey and road alignment works.

Topo Abney's level: It is bigger in size with bigger protractor. There are two faces of protractor - both graduated. The protractor can be removed and refixed with desired face. One side gives rise or fall for every 66 feet. The other side reads the percentage of rise and fall. We cannot read gradients. No vernier. This requires use of a Trailer tape in hilly country. When used with Trailer Tape, no mathematical calculation is needed. As there is no vernier, measurements cannot be said to be as accurate as in Abney's level.

23. HAGA ALTIMETER: It is another instrument used for measuring the heights of trees or other vertical objects. We need not use any trigonometric tables for this instrument. It is easily portable one.



23.1 Description: It consists of a gravity-controlled, damped, pivoted pointer and a series of rotatable scales on a hexagonal bar in a metal, pistol-shaped case. The top of the case is slightly rounded at the rear end. There is an eye piece S with a pin hole at the rear end. The sight vane which consists of a hollow metal tube of 1.5 cm long and 2 cm. in diameter with 2 prongs R protruding from the opposite sides inside the tube is located in the front end. The prongs are in a horizontal line. There is slight gap between the two.

There is a hexagonal bar inside the instrument just below the rounded top. This hexagonal bar can be rotated with a turning knob K on the

front face of the instrument in line with the bar inside. The bar has a separate scale on each of the face. The usual scales are 15, 20, 25, 30 and the percent 15, 20, 25 and 30 are the unit horizontal distances from the tree at which observer should stand to measure the height of object. The sixth scale is sometimes topographic and indicates heights directly for one chain horizontal distance. The scales are only in units. Hence the height of tree is indicated in the same unit. Suppose we stand at 20 metres distance from the tree, the height will be in metres. The scale is marked on the extreme left of the bar in a circle and the rest of the bar is graduated to indicate heights.

There is a longitudinal narrow slit or window <u>L</u> in metal case. This is covered by a glass <u>F</u>. The scale and height readings can be read through this glass. We can read only the scale being used and the height graduations can be seen. Other scales cannot be read. A gravity-controlled pointer moves along the scale. This indicates the heights above or below the eye-level. The pointer is narrow in width and wider in breadth. The top of the pointer is painted with white paint whereas the sides are painted with red. Thus error of parallax is avoided, while reading the scale. Since the pointer is gravity controlled, it is locked with a trigger <u>A</u>, when the instrument is idle or when the reading is to be taken. The pointer can be released by pressing the button <u>D</u>. There is a small hole <u>O</u> at the bottom of the butt. This will facilitate suspension of the instrument from our shoulder. The instrument can be kept in a leather case.

23.2 <u>Use of the Instrument</u>: Hold the instrument in your right hand by the pistol grip. Let the eye piece be towards you and sight-vane be towards the tree. Keep your fore-finger on trigger <u>A</u>. Stand at a distance of 15m or 20 or 25 or 30 metres from the tree. This distance should be approximately equal to the height of the tree. This distance should be the horizontal distance and not the sloping distance. Then turn the knob <u>K</u> so that it shows the scale at which distance you are standing. If you stand at 20m distance let the scale of 20m be seen through the slit or glass. Now press the button <u>D</u> and release the pointer. Now see the target i.e. top of the tree. Look through the pin hole of the eye piece <u>S</u>. Align with the sight prongs <u>R</u> and the top of tree. Be steady for few seconds. Let the pointer come to rest. Now press the trigger '<u>A</u>' to lock the pointer. Now read the scale and record. Without changing the position, observe the base of the tree in the same manner as explained above. Take the reading of the base. Add these two readings. This will give the height of the tree. Keep always your eye immediately above the pointer at the time of reading so that the red colour on its sides is not visible.

Suppose the height of the tree is so much that there is no scale equal to the horizontal distance, a scale equal to half of its height can be chosen. For example, for a tree of 40m height, select 20m scale. For a tree of 60m height select 30 scale. The readings taken from the instrument can be doubled to get the height of such trees.

Otherwise, the percentage scale may be used. The sum of the 2 readings to the top and base of the tree may be multiplied by the horizontal distance of the point of observation from the tree and divided by 100. Suppose the reading to the top is 100 and base is 30 from a point which was at 25m horizontal distance, the height of tree will be $\frac{(100 + 30) \times 25}{100}$ i.e. $\frac{130 \times 25}{100}$ = <u>32.5 metres</u>.

24. SOURCES OF ERROR IN HEIGHT MEASUREMENT: Following are the sources of errors in height measurements.

i) Errors due to instruments.
ii) Personal errors.
iii) Error due to method of measurement.
iv) Errors due to difficulty in sighting the objects.
v) Errors due to leaning trees.

Let us study them one by one.

i) Errors due to Instruments: These errors occur due to some deficiency in instruments. We always believe that the instruments are correct. They have to be tested and corrected or adjusted before use. But there are certain drawbacks in the instruments also. Few examples are given:

a) Index error of Abney's level. This can be adjusted with the help of screws, controlling the movements of index arm and spirit level.

b) If a chain which is short is used, for measuring the distances, it will give excess chainage. This excess may be calculated and deducted from the total chainage.

c) Brandis hypsometer may show +1° error while measuring angles of elevation. This 1° may be deducted from the angle of elevation or depression.

d) Christen's hypsometer may be going on swinging due to wind and aking reading may be difficult.

e) While turning Smythies' hypsometer, to read the reading, the plumb bob may slip and thereby may give a wrong reading.

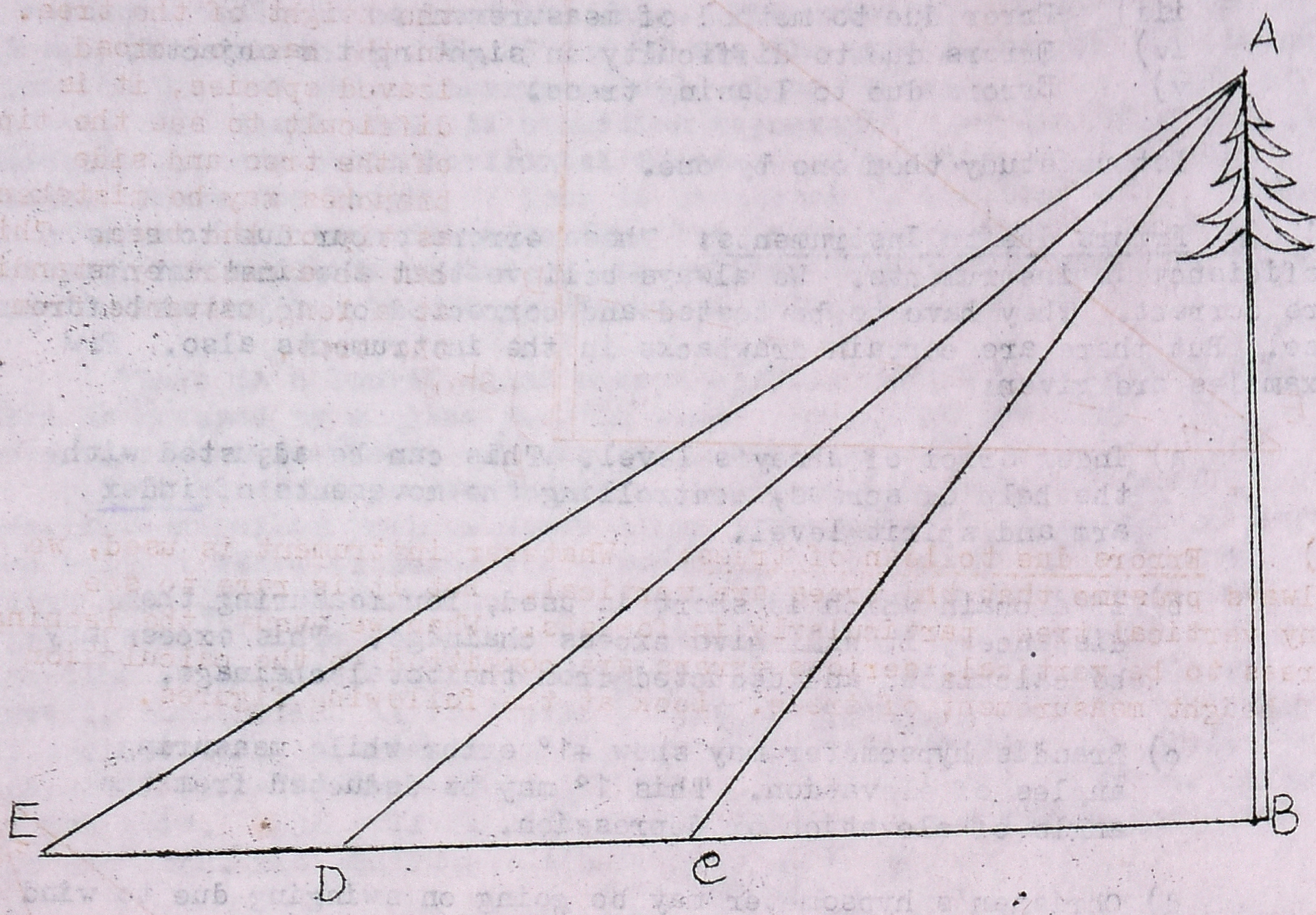
f) In Brandis hypsometer, the wheel will be going on swinging and test the patience of observer and he may remove the finger from the spring and lock the wheel even when it is swinging slightly. This will give inaccurate reading.

The instruments should be tested and adjusted before they are put to use. If the instruments give errors in excess of permissible limits which can neither be eliminated nor corrected, the instruments will have to be discarded.

ii) Personal Errors: The amount of this error will vary from person to person, depending upon their skill in handling the instrument. The observer should be steady at the time of measuring the angles. Shaking hand will give inaccurate results. He must have a good sight power.

iii) Errors due to method of measurement: Experience shows that the observer should always stand at a distance approximately equal to the height of the tree.

a) Supposing the observer stands at D, at a distance of 50m, and the angle of elevation is 45°, then the height of tree above eye level is Tan 45 x 50 = 50m. Suppose in the angular measurement, there is an error of 1° i.e. 44°, the height will be Tan 44 x 50m i.e. 0.9657x50 = 48.285m. Hence the error is 1.715m. and the percentage of error is 3.43%.



b) Suppose the observer stands at E, which is 100 metres from the tree, the angle of elevation may be 25°33' instead of 26°33'. The tree height will be Tan 25°33' x 100 i.e. 47.18m. This gives a percentage of error as 4.38%.

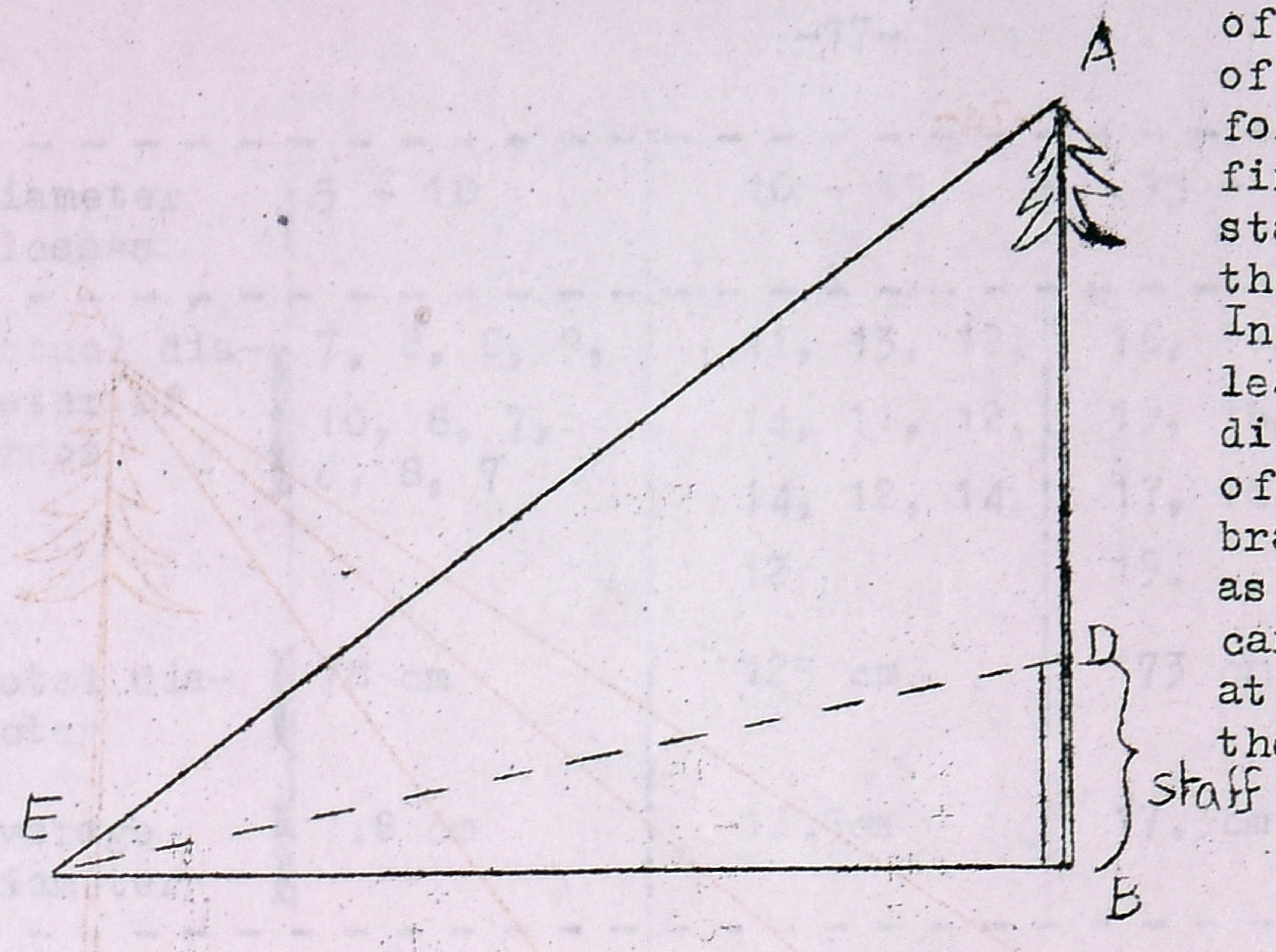
c) Suppose the observer stands at C which is at a distance of 25m and commits the same error, the angle of elevation will be read as 62°27' instead of 63°27'. This will give the height as Tan 62°27'x25 i.e. 47.925 m. Percentage of error works out to 4.15%.

Hence it is clear that the observer should as far as possible be at distance approximately equal to the height of tree so that percentage of error will be minimum.

d) Next comes the measurement of horizontal distances. If a tape is used for measuring the distance between the tree and observer in an area which is full of weeds and thorny bushes or when measurements are taken where there is strong wind, the measurements taken will not be correct. Stepping measurements if not done properly, will be inaccurate.

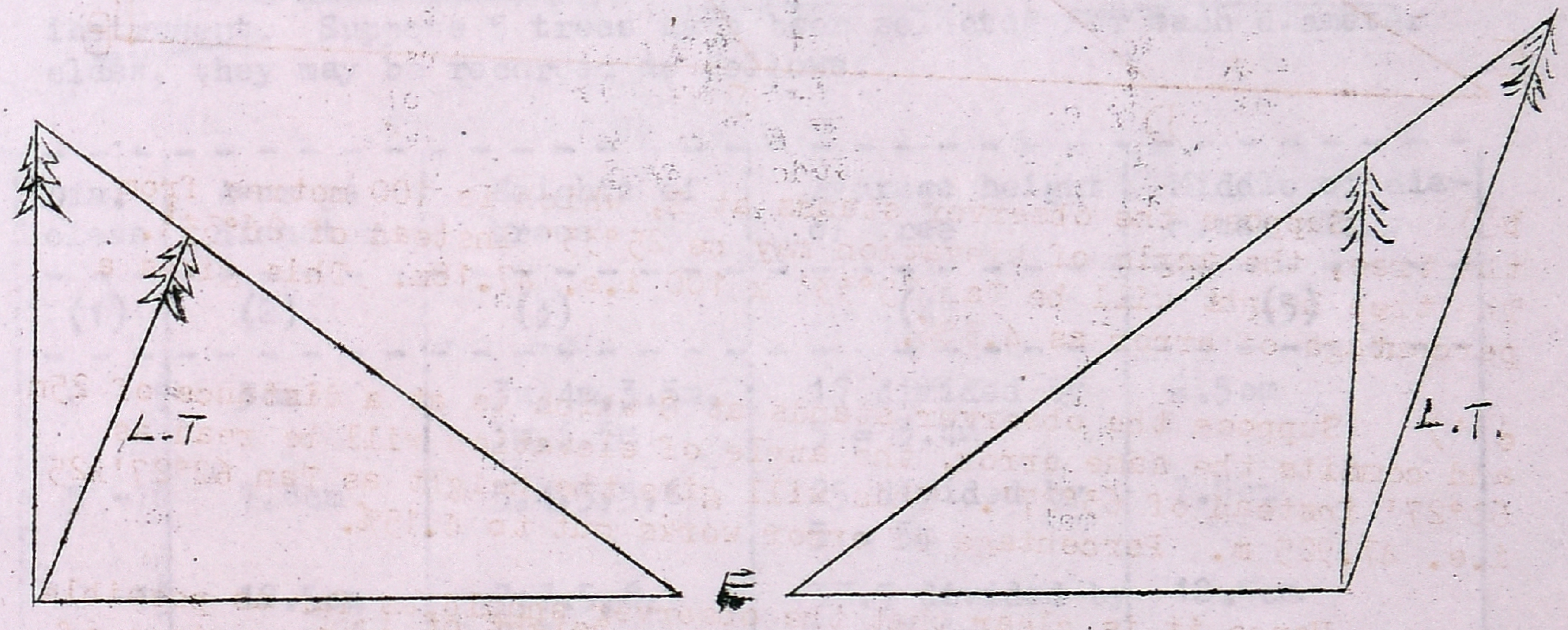
iv) Errors due to difficulty in observation:

Mostly it will be very difficult to the observer to see the top and base of the tree. Particularly the undergrowth obstructs the base of the tree. In such cases, a staff may be kept at the base



of the tree and the top of the staff may be seen for measurements and finally the length of the staff may be added to get the height of the tree. In the case of broad leaved species, it is difficult to see the tip of the tree and side branches may be mistaken as tip of the tree. This can be avoided by standing at a long distance from the tree.

v) <u>Errors due to lean of trees:</u> Whatever instrument is used, we always presume that the trees are vertical. But it is rare to see any vertical tree, particularly in forests. When we assume the leaning trees to be vertical, serious errors are committed in the calculation of height measurement of trees. Look at the following figures.



Leaning trees can be seen. The vertical height calculated is also seen. It can be easily understood from the figures that the trees leaning towards observer is over-estimated and tree leaning away from the observer is under-estimated.

Chaturvedi has calculated that for a lean of <u>d</u>°, the percentage error is

$$\left\{ \frac{\cos(\theta \pm d)}{\cos \theta} - 1 \right\} \times 100$$ for the trees leaning

towards the observer and away from the observer. According to him, the following is the percentage error for various values of <u>d</u> (angle of lean) and θ (angle of elevation).

Diameter classes	5 - 10	10 - 15	15 - 20	20 - 25
Actual diameter of trees	7, 8, 8, 9, 10, 8, 7, 6, 8, 7	11, 13, 12, 14, 11, 12, 14, 12, 14, 12	16, 18, 17, 19, 16, 18, 17, 16, 17, 19.	21, 24, 25, 23, 24, 22, 24, 25, 22, 24
Total diameter	78 cm	125 cm	173 cm	234 cm
Average diameter	7.8 cm	12.5cm	17.3cm	23.4cm

Hence select trees which will have the average diameter i.e. 7.8cm, 12.5cm, 17.3cm and 23.4cm in the above case -- or trees which are very near to this diameter. The number of trees to be selected in each group depends upon the total number of trees available in each group.

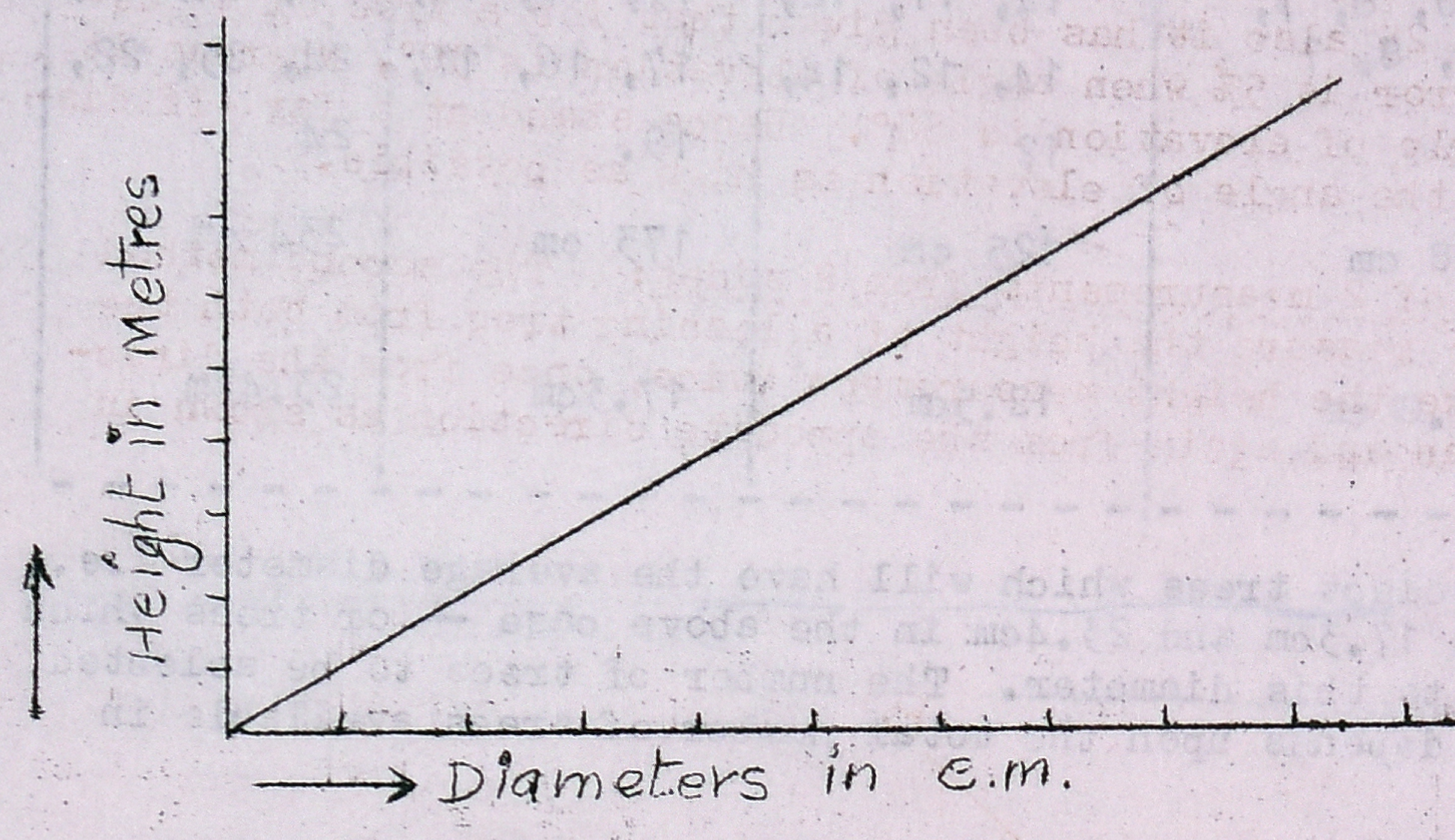
Heights of these selected trees can be measured with any instrument. Suppose 5 trees have been selected for each diameter class, they may be recorded as follows:

Dia. class	Average diameter	Heights of trees	Average height of tree	Middle of diameter class
(1)	(2)	(3)	(4)	(5)
0 - 5	3cm	3m,4m,3.5m, 3m,3.5m	17 divided by 5 = 3.4m	2.5cm
5 -10	7.8cm	5,4,5,5,6	25 divided by 5 = 5m	7.5cm
10 -15	12.5cm	7,7.5,8, 8,7	37.5 divided by 5 = 7.5m	12.5cm
15 -20	17.3cm	9,11,10, 11,12	53 divided by 5 = 10.6	17.5cm
20 -25	23.4cm	14,15,17, 16,16	78 divided by 5 = 15.6m	22.5cm

Col.2 and 4 or col.4 and 5 can be separately written.

Dia.	2.5	7.5	12.5	17.5	22.5	etc..
Ht.	3.4	5.0	7.5	10.6	15.6	etc..

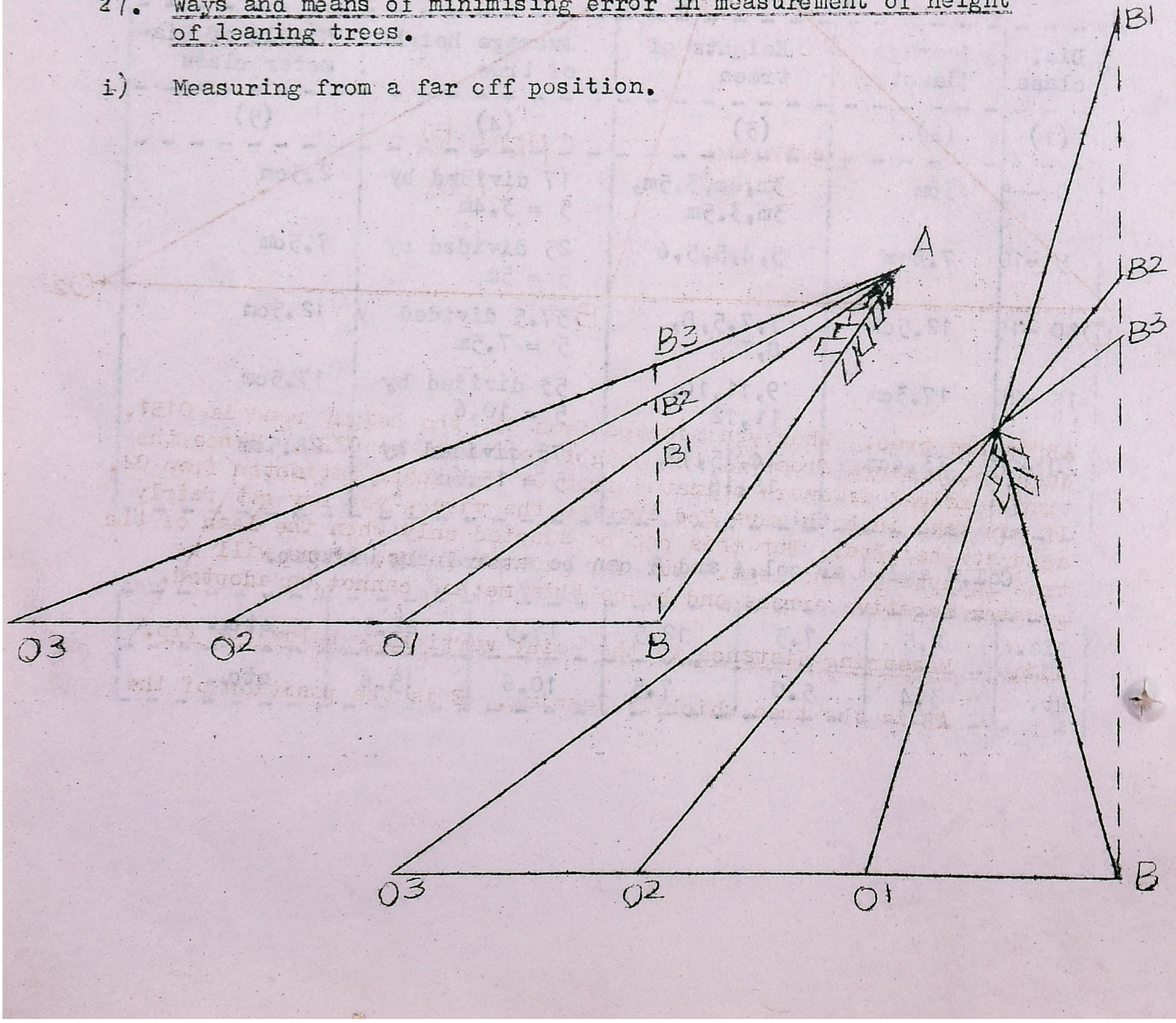
This may be plotted in a graph paper by plotting DBH in X axis and height in Y axis after selection of proper scale.



From the above graph, a table may be prepared showing the diameters of trees and the corresponding heights and this table is known as the Diameter-height table.

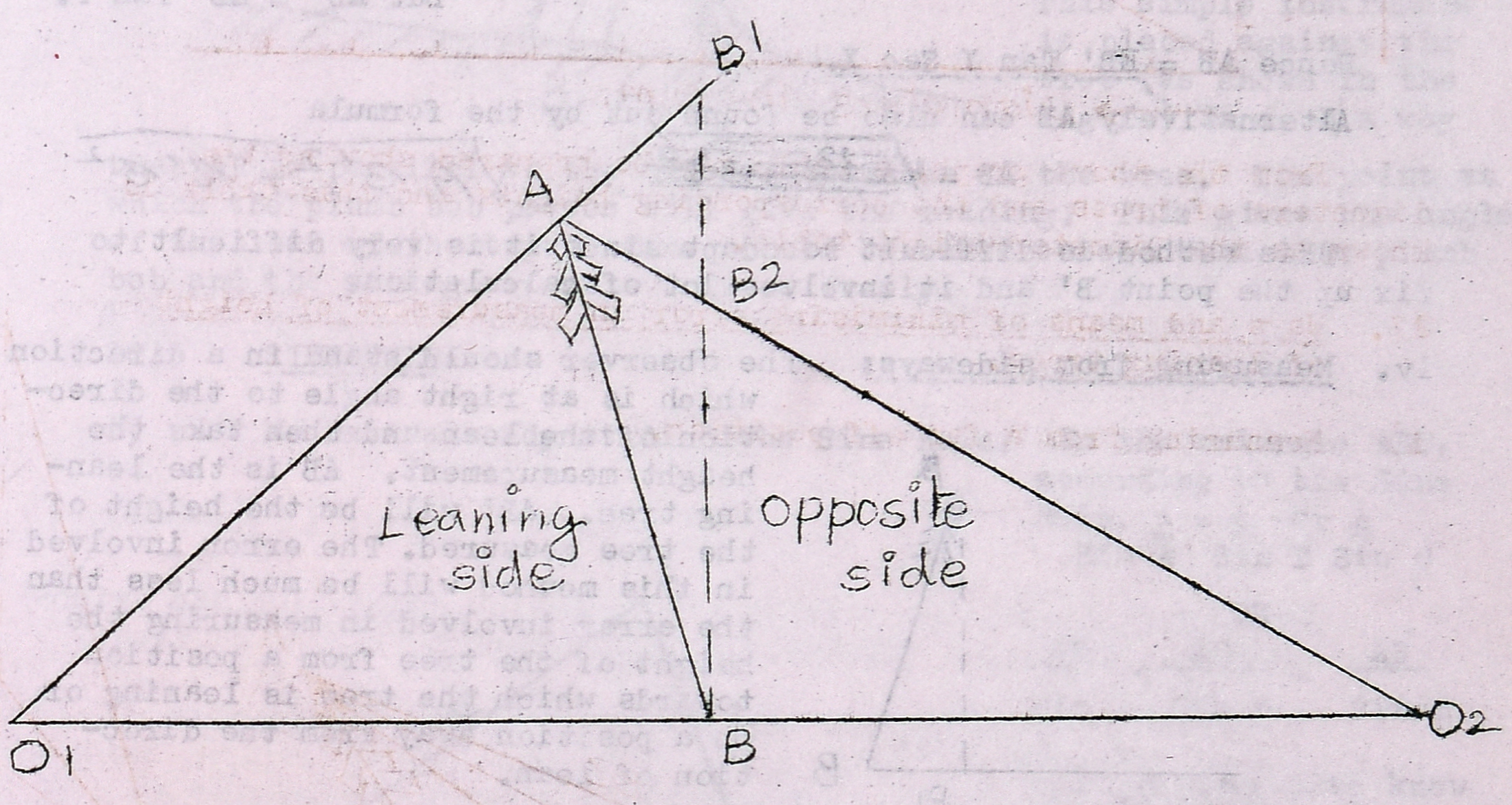
27. <u>Ways and means of minimising error in measurement of height of leaning trees.</u>

i) Measuring from a far off position.



Look at the above figures. AB is the leaning tree, one towards the observer and other away from the observer. 01, 02, 03 are the position of observers in each case. The dotted lines BB1, BB2 and BB3 will show the position of vertical line. Suppose we measure from 01, the 01B1 will be the height measured since we presume that the tree is vertical. Similarly 02B2 and 03B3 will be the heights when measured from 02 and 03 positions respectively. This clearly proves that we must stand at as great a distance from the tree as possible so that the error will be minimised. In the table given under V of para 25 also it has been given that for a tree of 5° deviation, the error is 5% when angle of elevation is 30°, whereas it is 15% when angle of elevation is 60°. Hence stand at a far off distance and keep the angle of elevation as high as possible.

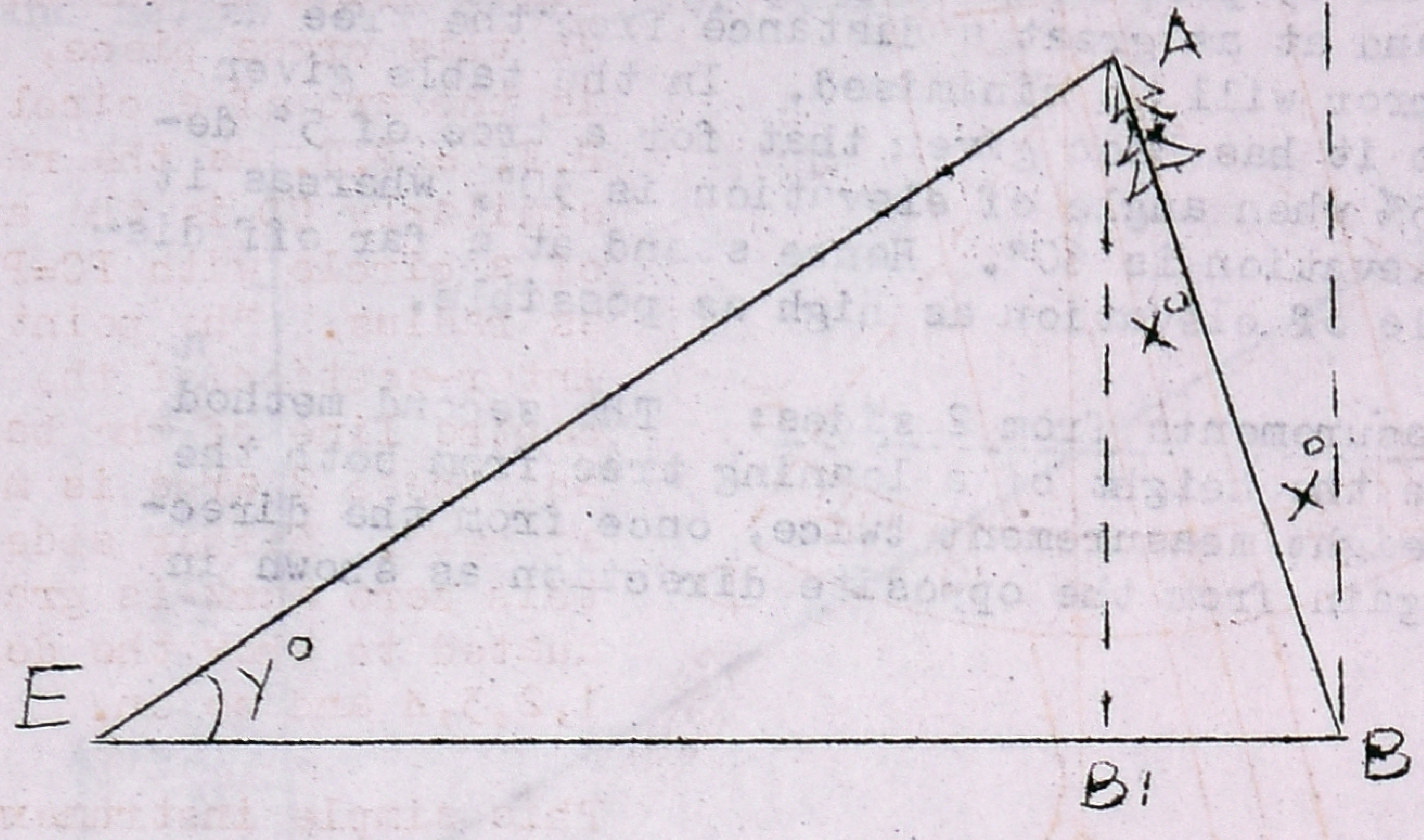
ii. Averaging of 2 measurements from 2 sides: The second method suggested is to measure the height of a leaning tree from both the sides i.e., take the height measurement twice, once from the direction of the lean and again from the opposite direction as shown in the figure.



AB is the tree. When you measure from 01, the height read is 01B1. When you measure from 02, the height read will be 02B2. Hence the tree's height is over-estimated from 01 and under estimated from 02. If you take in both ways and average the value, you may get fairly accurate heights. But this can be adopted only when the lean of the tree is upto 5° and less. But for greater leans, there will be greater negative errors and hence this method cannot be adopted.

iii. Measuring distance to the point vertically below the Tip.

AB is the tree which is leaning. E is the position of the



observer. Now measure the angle of elevation to the top of the tree and the distance EB' instead of EB, since B' is the point vertically below the tip of the tree. Hence height of tree will be i.e. AB = EB' Tan Y. Let the angle of deviation from vertical be x°.

$\text{Sec } x = \frac{AB}{AB'}$

Hence AB = AB'Sec x.

But AB' = EB' Tan Y.

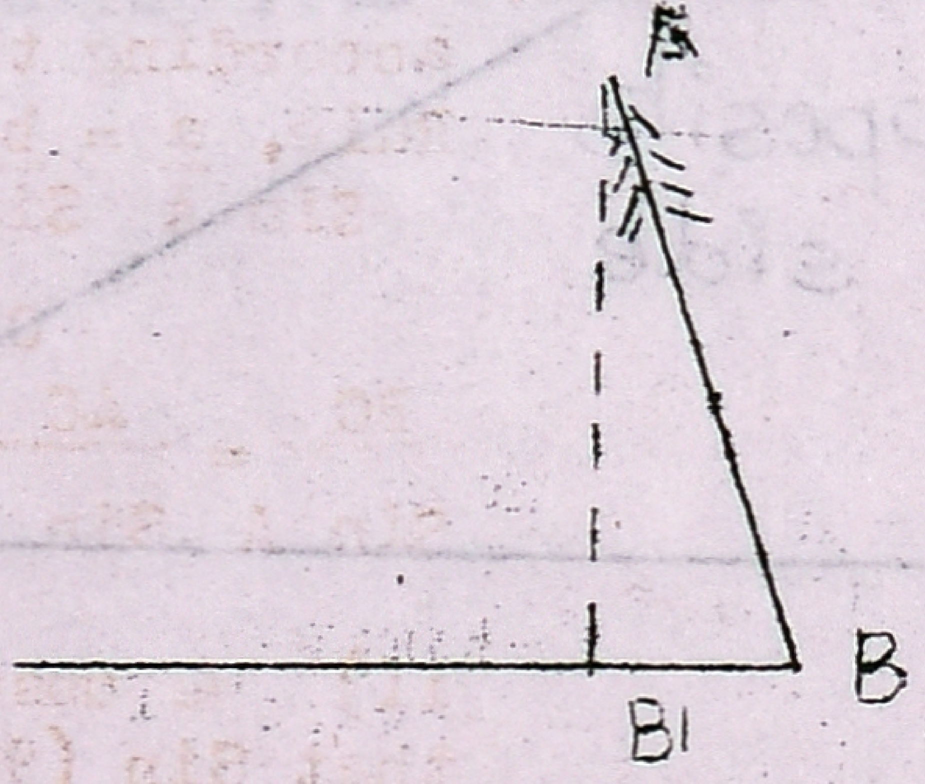
Hence AB = <u>EB' Tan Y Sec X.</u>

Alternatively AB can also be found out by the formula

$$AB = \sqrt{AB'^2 + B'B^2} = \sqrt{AB'^2 + B'B^2}$$

This method is difficult to adopt since it is very difficult to fix up the point B' and it involves lot of calculation.

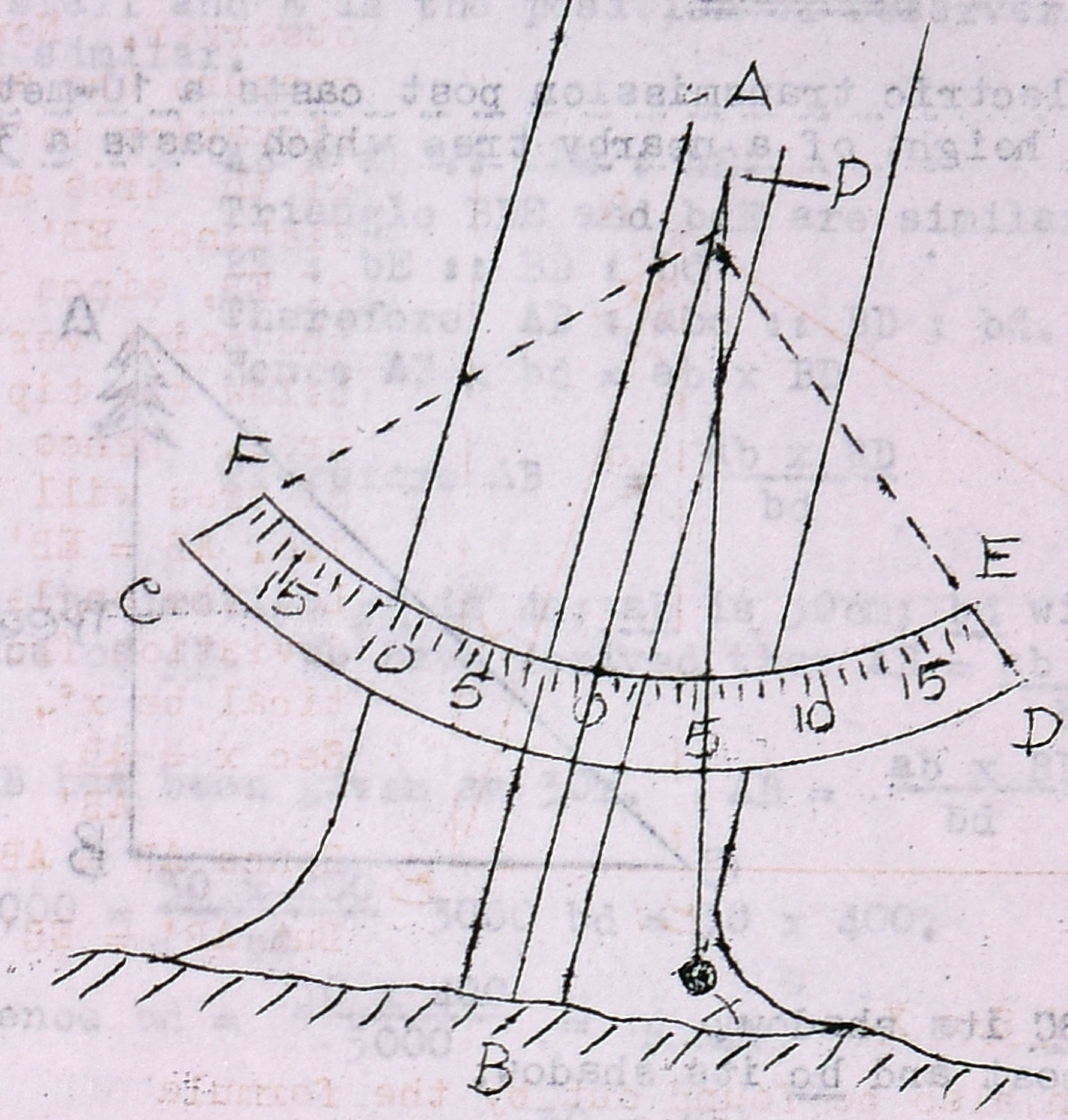
iv. <u>Measuring from sideways:</u> The observer should stand in a direction which is at right angle to the direction of the lean and then take the height measurement. AB is the leaning tree. AB' will be the height of the tree measured. The error involved in this method will be much less than the error involved in measuring the height of the tree from a position towards which the tree is leaning or in a position away from the direction of lean.



28.1 <u>MEASUREMENT OF HEIGHT OF LEANING TREES:</u>

In the above paragraph we saw how to minimise the errors. But there will be errors whenever we assume that the leaning trees are vertical. Hence it is quite essential to know and as to how the leaning trees should be measured accurately. Before that we have to know the method of measuring the angle of lean of the trees.

28.2 <u>How to measure angle of lean?</u> A simple instrument has been devised by Krishnaswamy. AB is a smooth batten which is of rectangular section with 1.5 to 1.8 m length with a centre lines drawn in it in the broad face. At one end of the line, a hole is bored. A



thin string and a plumb bob is suspended through this hole. At a distance of about 45cm from A,B, a cross piece CDEF is fixed flush to the batten. In this cross piece, FE is the arc of a circle with P.F. = P.E. as the radius; similarly CD is the arc of a circle with PC=PD as radius. The point of inter-section of the centre line of the batten and these 2 arcs is marked as zero. Either side of this zero mark is graduated to show the degrees 1,2,3,4 and so on.

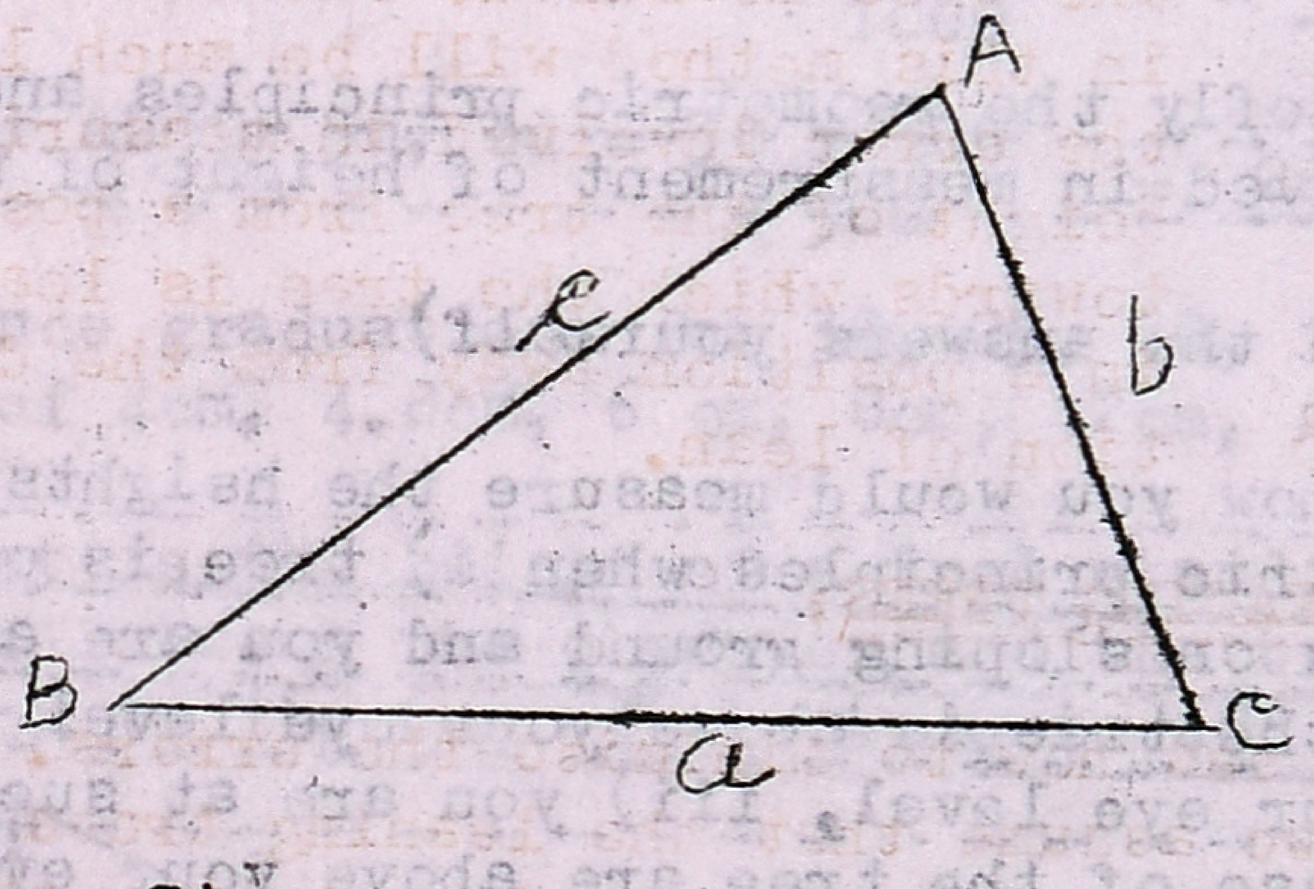
This simple instrument is placed against the tree (as shown in the figure) in such a way that AB is parallel to the axis of the lean of the tree. The point at which the plumb bob passes will give the reading. This gives the angle of the lean of the tree. Care should be taken to see that this plumb bob and the string are able to move freely.

28.3 SINE RULE:

i) We have already studied the Sine Rule. In the triangle ABC, according to the Sine Rule, $\frac{a}{\text{Sin } A} = \frac{b}{\text{Sin } B}$ or $\frac{c}{\text{Sin } C}$

OR

$$\frac{BC}{\text{Sin } A} = \frac{AC}{\text{Sin } B} = \frac{AB}{\text{Sin } C}$$

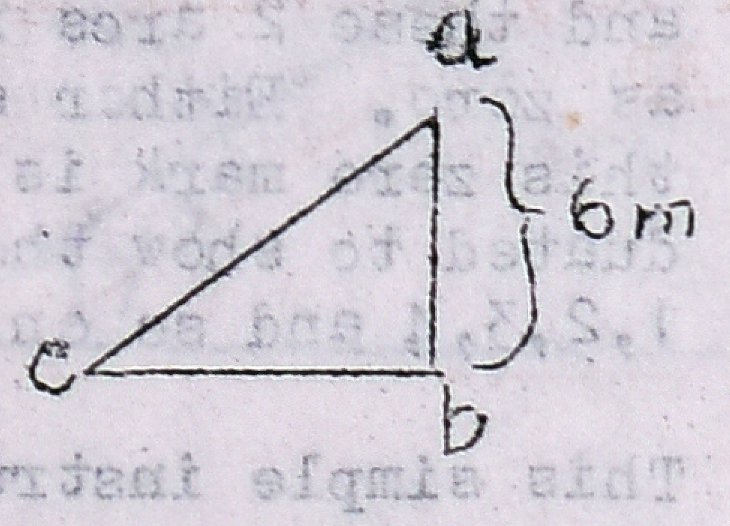


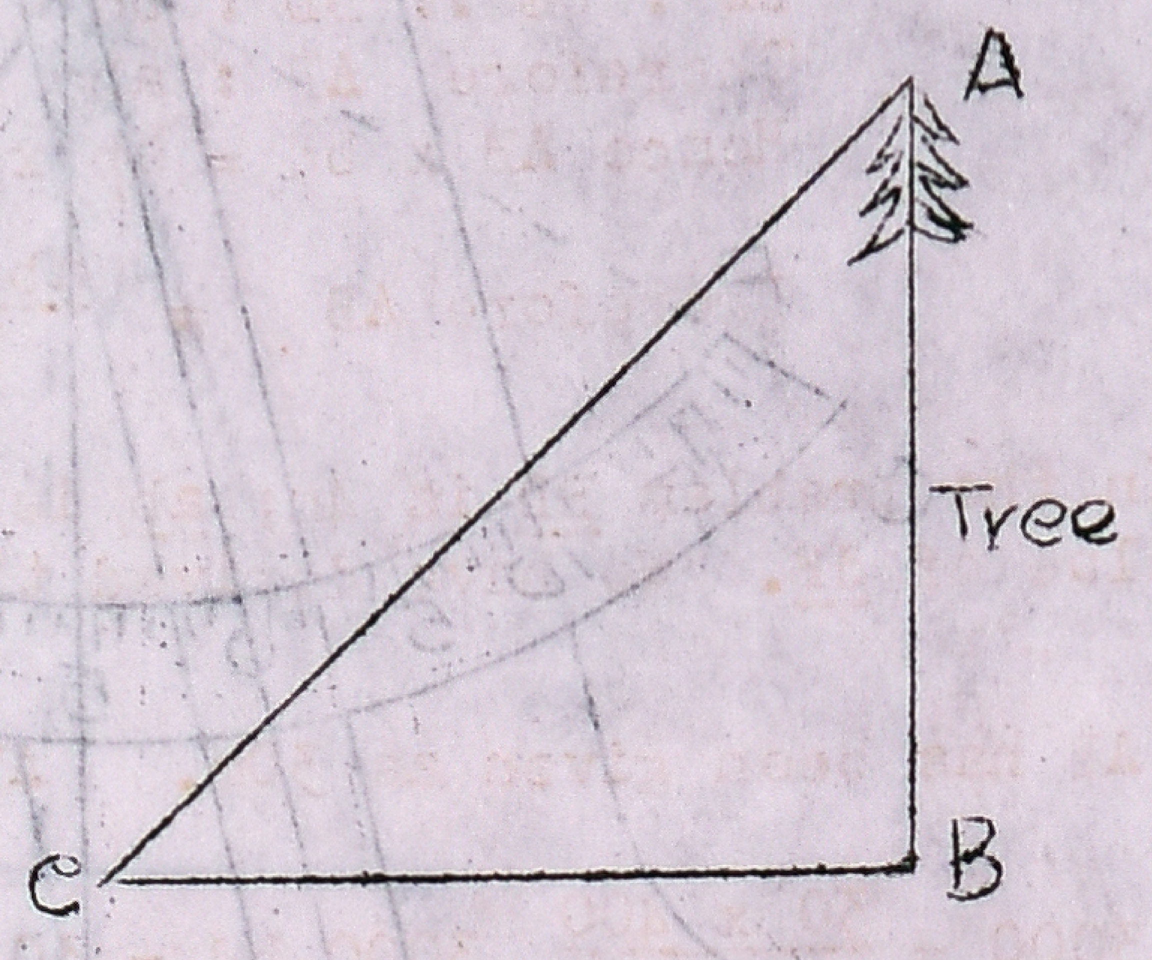
ii) We must also know that Sin (90 - X) = Cos X. These rules may be applied in measurement of height of leaning trees.

Note: Since measurement of height of leaning trees is not in our syllabus, a chapter on the measurement of height of leaning trees has been added in Appendix.

PROBLEMS

1. If a 6 metre high electric transmission post casts a 10-metre long shadow, what is the height of a nearby tree which casts a 30m long SHADOW?





Let AB be the tree and BC its shadow.
Let ab be the electric post and bc its shadow.

$\frac{AB}{ab} = \frac{BC}{bc}$ i.e. $\frac{AB}{6} = \frac{30}{10}$ Hence 10AB = 180m; AB = 18m.

2. If a 8-metre high electric transmission pole casts a 12-metre long shadow, what is the height of a nearby tree which casts a 40m. shadow? See the above sketch.

Here AB is the tree; ab is 8m; BC is 40m. and bc is 12m.

$\frac{AB}{ab} = \frac{BC}{bc}$ i.e. $\frac{AB}{8} = \frac{40}{12}$ Hence 12 AB = 320. AB = 26.67 m.

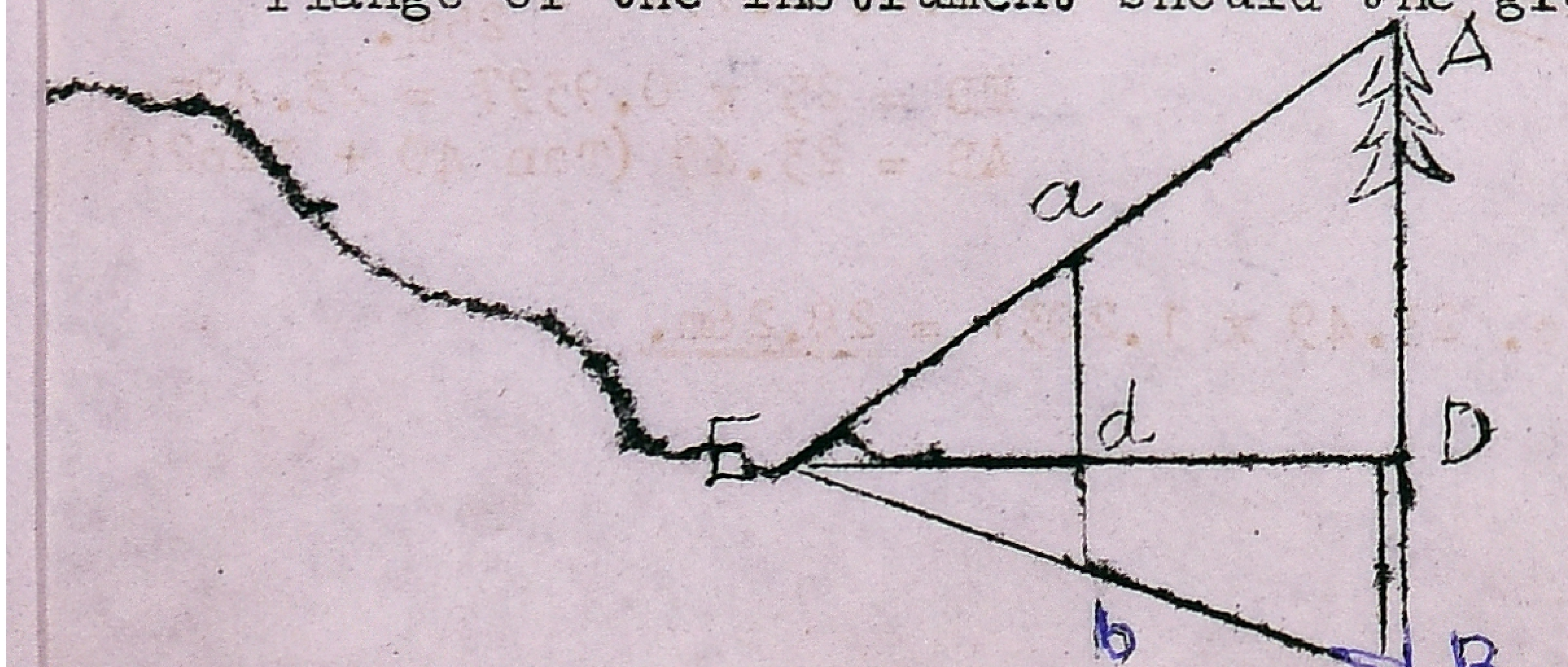
3. Explain with sketches briefly the geometric principles and trigonometric principles involved in measurement of height of trees.

(Prepare the answers yourself)

4. Explain, with sketches, how you would measure the heights of trees based on Trigonometric principles when i) tree is on level ground; ii) tree is on sloping ground and you are at such a place that the top of the tree is above your eye level and base of tree is below your eye level, iii) you are at such a place that the top and base of the tree are above your eye level; iv) you are at such a place that the top and base of the tree are below your eye level.

(Prepare the answers yourself)

5. The length of Christen's hypsometer between its flanges is 30cm and length of the staff used is 4m. At what distance from the lower flange of the instrument should the graduations be made to read heights of 30, 25, 20, 15 and 5 metres.



The principle of graduation is based on similar

triangles. In the figure, AB is the tree; ab is the hypsometer, DB is the staff and E is the position of observer. Triangles ABE and abE are similar.

AB : ab :: BE : bE.
Triangle BDE and bdE are similar.
BE : bE :: BD : bd
Therefore AB : abc :: BD : bd.
Hence AB x bd = ab x BD

$$\text{Therefore AB} = \frac{ab \times BD}{bd}$$

In the problem BD is 4m; ab is 30cm; bd will vary depending upon the value of dB. We have derived that $AB = \frac{ab \times BD}{bd}$.

a) AB has been given as 30m. $AB = \frac{ab \times BD}{bd}$

$3000 = \frac{30 \times 400}{bd}$ 3000 bd = 30 x 400.

Hence $bd = \frac{30 \times 400}{3000} = $ 4 cm.

b) If AB is 25m, $2500 = \frac{30 \times 400}{bd}$

i.e. 2500 bd = 30 x 400; $bd = \frac{30 \times 400}{2500} = $ 4.8 cm.

c) If AB is 20m, $bd = \frac{30 \times 400}{2000} = $ 6 cm.

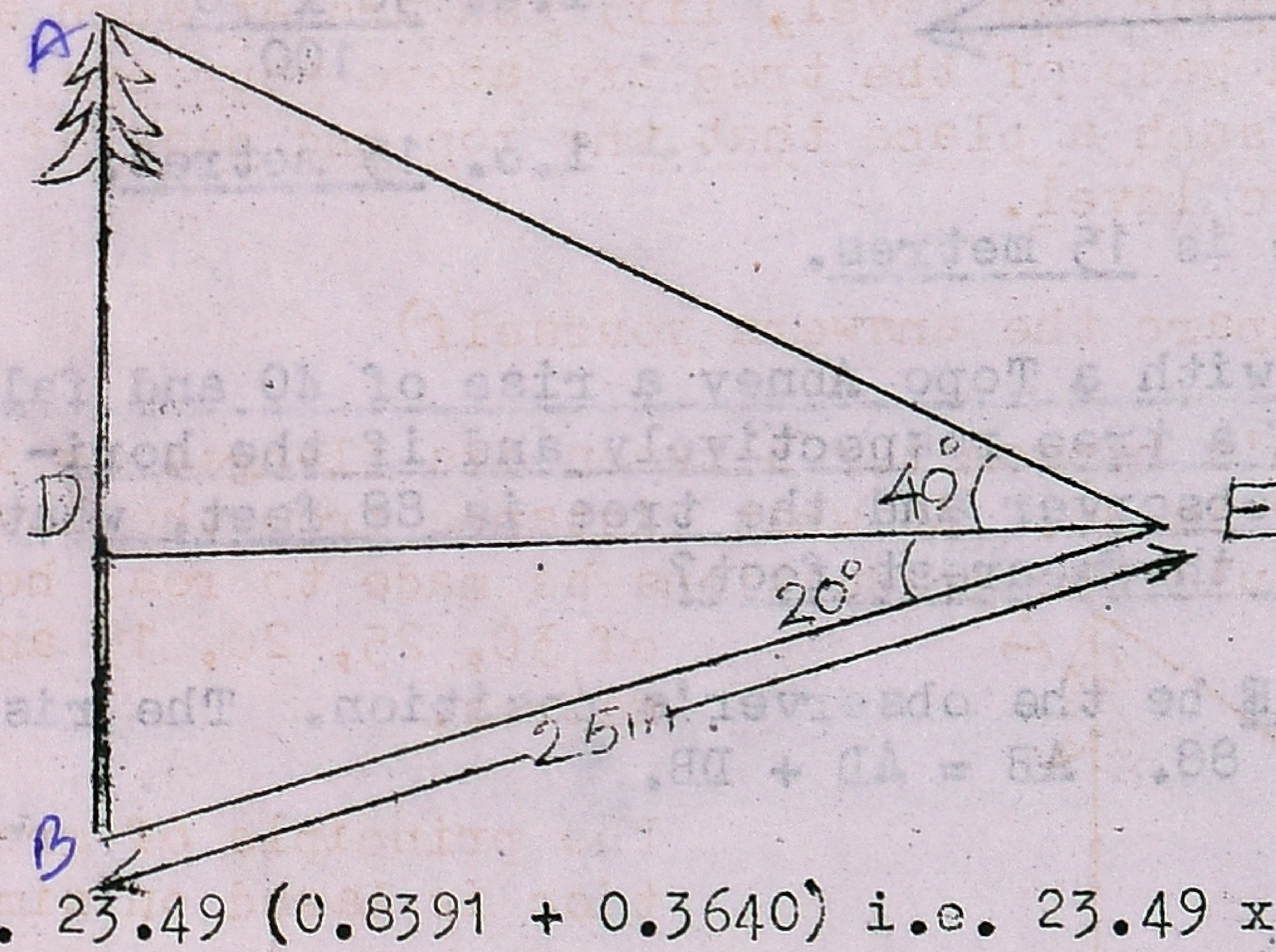
d) If AB is 15 m, $bd = \frac{30 \times 400}{1500} = $ 8 cm.

e) If AB is 10 m, $bd = \frac{30 \times 400}{1000} = $ 12 cm.

f) If AB is 5m, $bd = \frac{30 \times 400}{500} = $ 24 cm.

Hence graduations for 30, 25, 20, 15, 10 and 5m will be at distances of 4cm, 4.8cm, 6 cm, 8cm, 12cm, and 24cm from the lower flange.

6. What is the height of a tree standing on sloping ground if the distance between the observer and the tree is 25m and the angle of elevation to the top of the tree is 40° and angle of depression is 20°?



AB is the tree; E is the observer's position. Take the triangle ∠DEB. ∠DEB is 20°. EB is 25m.

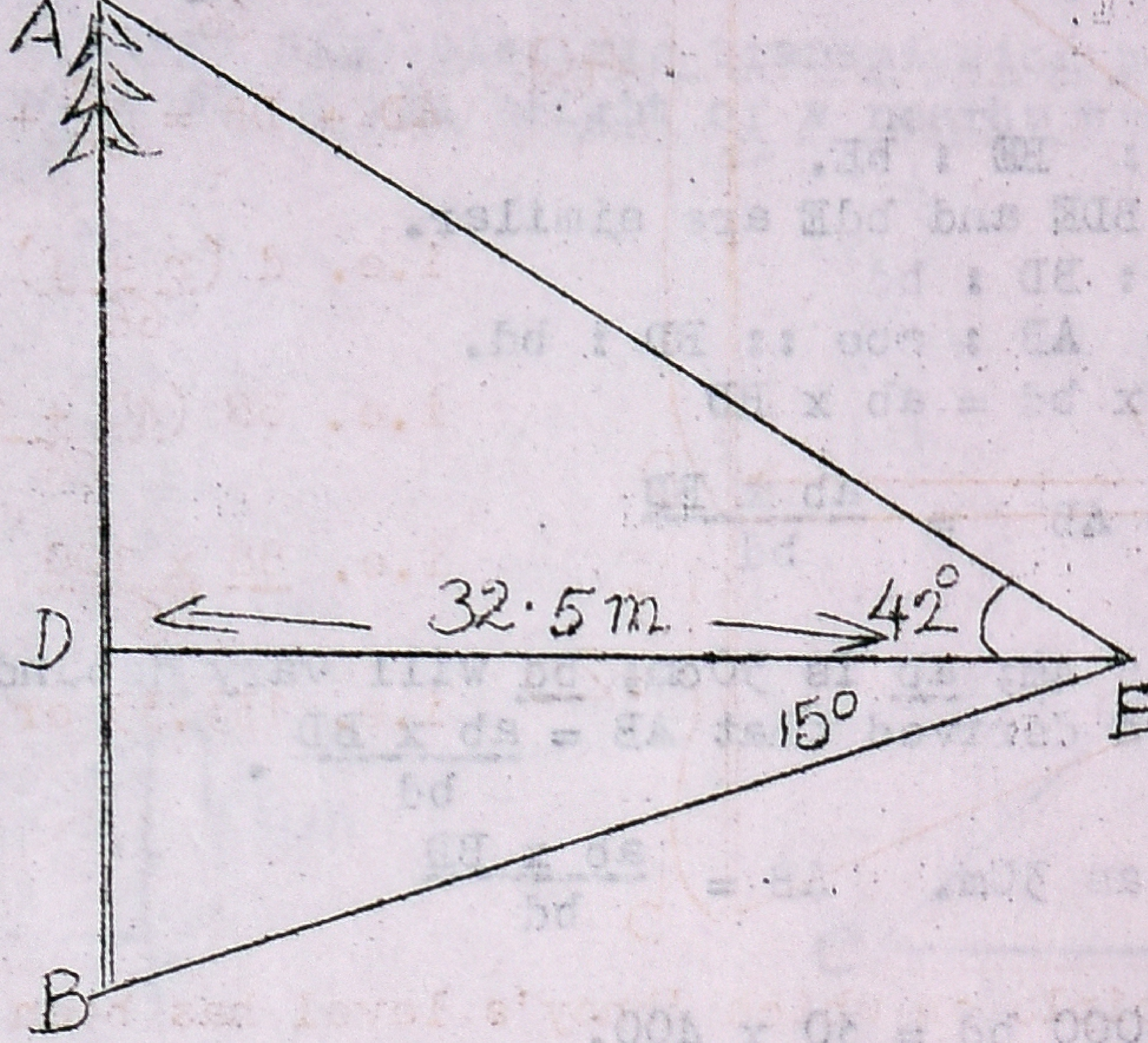
$\text{Cos } 20° = \frac{ED}{BE}$

i.e. $0.9397 = \frac{E.D}{25m.}$

ED = 25 x 0.9397 = 23.49m.
AB = 23.49 (Tan 40 + Tan20)

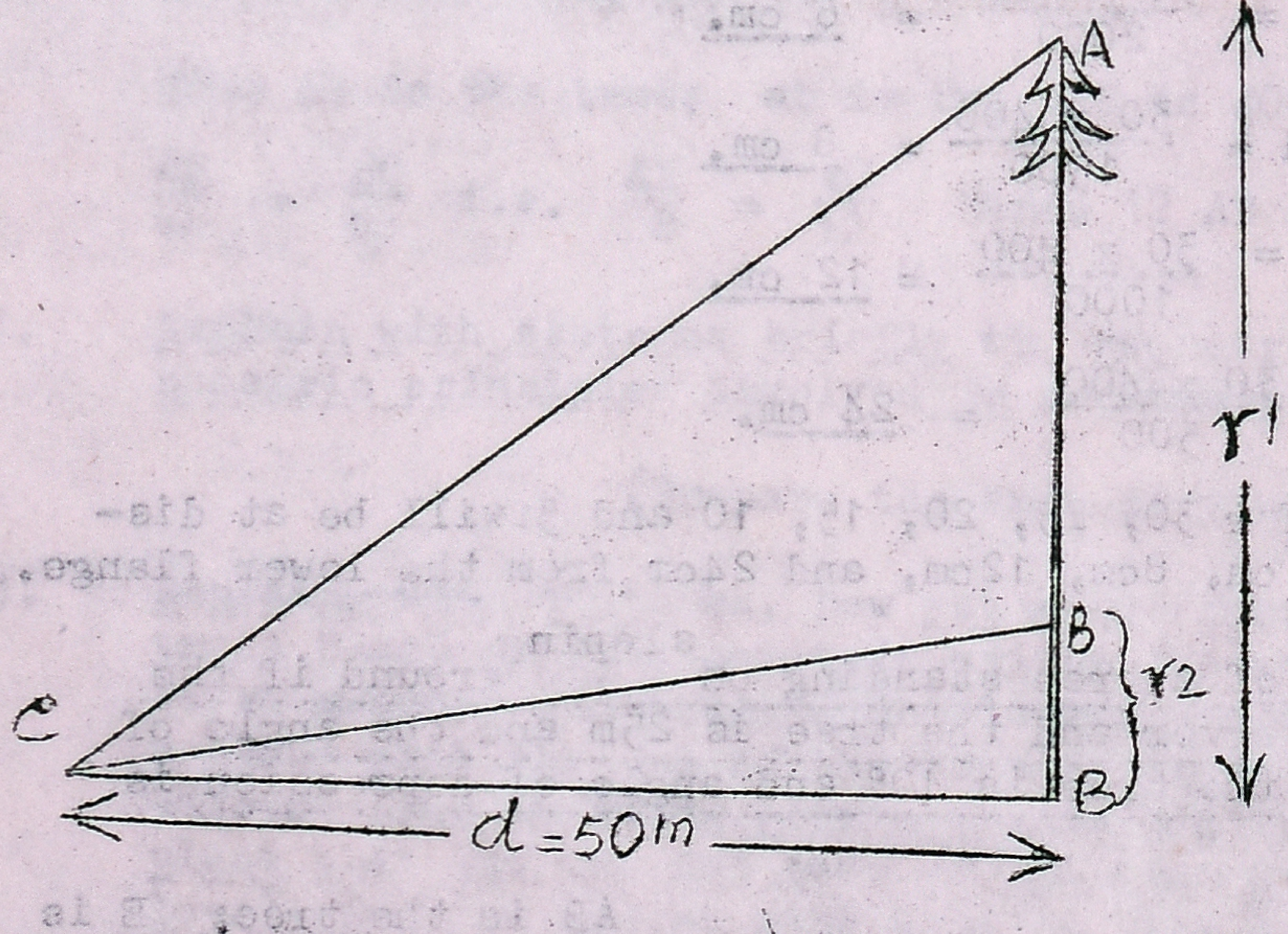
i.e. 23.49 (0.8391 + 0.3640) i.e. 23.49 x 1.2031 = 28.26m.

7. The angle of elevation is 42°. Angle of depression is 15°. The horizontal distance between observer and base of tree is 32.5m. Find out the height of tree.



AB is the tree. E is observer.
Given ∠DEA = 42° and ∠DEB is 15° and DE is 32.5m.
AB = ED (Tan X + Tan y)
AB = 32.5 (Tan 42 + Tan 15) i.e. 32.5 (0.9004 + 0.2679)
i.e. 32.5 (1.1683)
i.e. 37.97 metres. Ans.

8. A Topo Abney reads 40 and 10 as rise percentage to the top and base of the tree (standing above the eye level of the observer) respectively. The horizontal distance between the observer and base of the tree, as measured with a Trailer Tape is 50 metres. What is the height of the tree?



Let AB be the tree and E the observer's position. ED is given as 50m. r1 is 40 and r2 is 10. AB = AD - BD

$$AD = \frac{d \times r1}{100}$$

$$BD = \frac{d \times r2}{100}$$

$$AD - BD = \frac{dr1}{100} - \frac{dr2}{100}$$

$$\text{i.e. } d\ \frac{(r1 - r2)}{100}$$

$$\text{i.e. } 50\ \frac{(40 - 10)}{100}$$

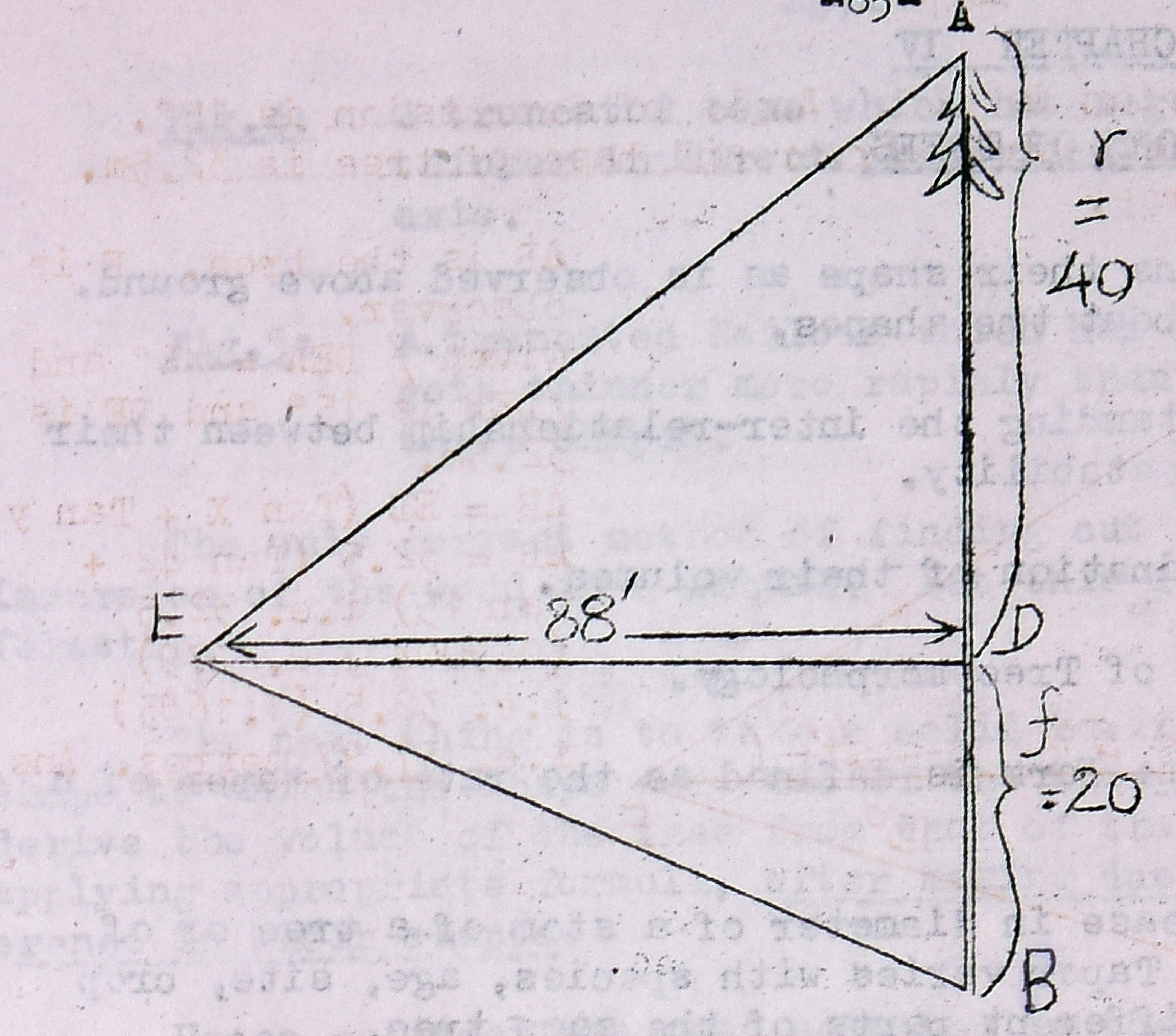
$$\text{i.e. } \frac{50 \times 30}{100}$$

i.e. 15 metres.

Hence height of tree is 15 metres.

9. If the observer reads with a Topo Abney a rise of 40 and fall of 20 to the top and base of a tree respectively and if the horizontal distance between the observer and the tree is 88 feet, what is the height of the tree to the nearest foot?

Let AB be the Tree and E be the observer's position. The rise is 40 and fall is 20 and d = 88. AB = AD + DB.



$$AD = \frac{d \times r}{66}$$

$$DB = \frac{d \times f}{66}$$

$$AD + DB = \frac{dr}{66} + \frac{df}{66}$$

i.e. $d \frac{(r + f)}{66}$

i.e. $88 \frac{(40 + 60)}{66}$ 2° ✓

i.e. $\frac{88 \times 100}{66}$

i.e. 133.33 or 133 feet.

10. Explain the principle on which Abney's level has been constructed. Describe the instrument briefly and explain how you would measure the height of trees with a Abney's level.

11. Briefly describe a Topo Abney and Trailer Tape and explain how these instruments can be used to measure the height of trees.

12. Name the instruments that are used for measuring heights of trees based on Geometric and Trigonometric principles. Describe any one instrument under geometric principles and how will you find the height of the tree with this instrument?

CHAPTER IV

FORM OF TREES

1. Form of Trees means their shape as is observed above ground. It is necessary to know about the shapes,

   i) For understanding the inter-relationship between their shapes and stability.

   ii) For determination of their volumes.

   iii) As a study of Tree morphology.

2. Definition of Form: Form is defined as the rate of taper of a log or stem.

Taper is the decrease in diameter of a stem of a tree or of a log from base upwards. Taper varies with species, age, site, crop density and also in the different parts of the same tree.

3. Concept of Taper: The shapes of trees do not conform to any regular geometric shape. This makes us difficult to get a formula for the calculation of the volume.

See the figure 1. The basal portion of the tree corresponds to the frustrum of a Neiloid. The middle portion to the frustrum of a paraboloid and top portion to that of a cone.

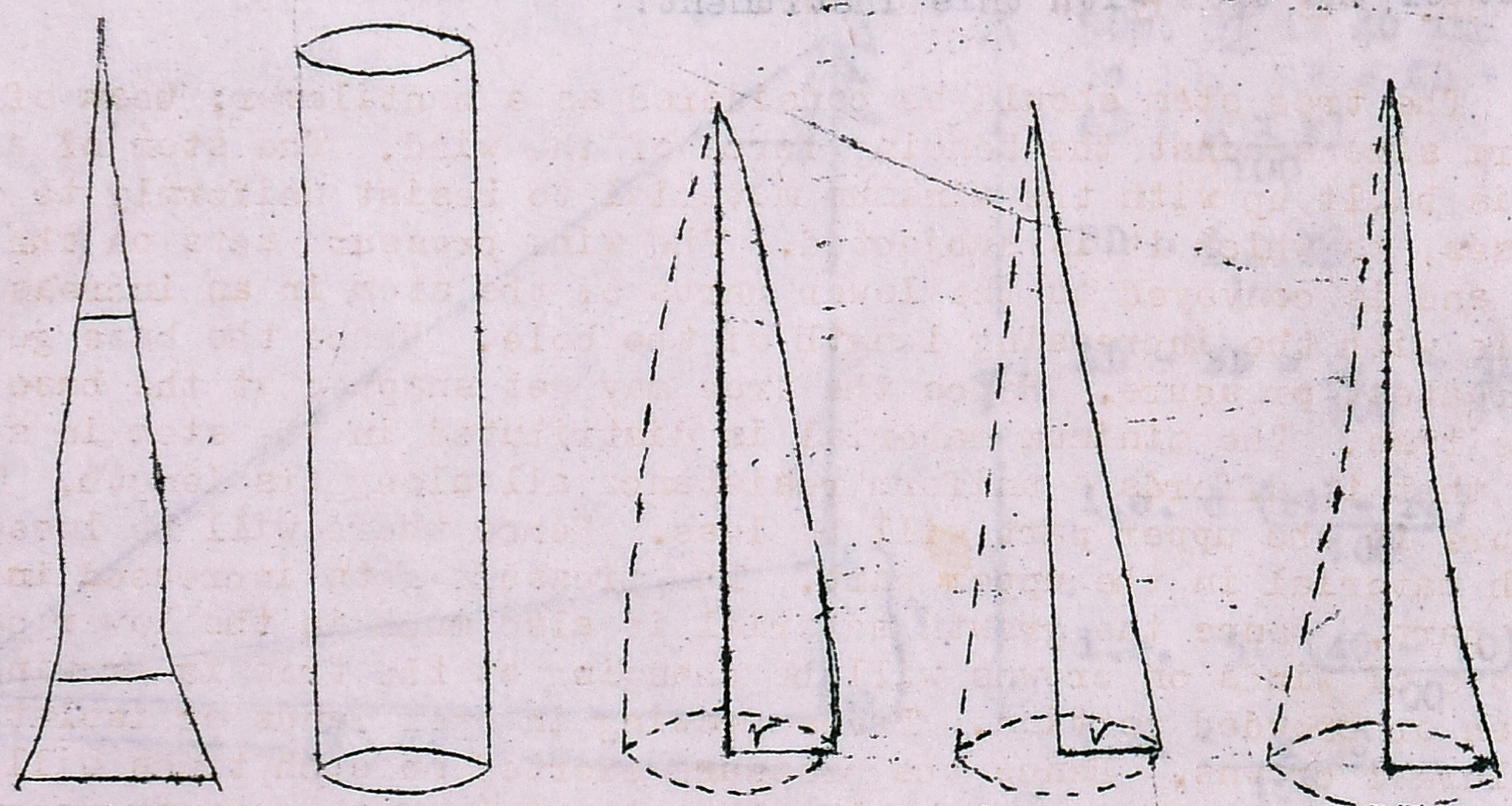


Fig.1 Fig.2 cylinder Fig.3 Paraboloid Fig.4 cone Fig.5 Neiloid

The trees may also look in the shapes of cylinder, paraboloid, cone, Neiloid, etc. as shown in figures 2,3,4 and 5.

Fig.2: Represents a cylinder which has no taper.

Fig.3: A truncated paraboloid which slowly gets thinner towards its top i.e., has slight taper.

Fig.4: A truncated cone which has regular taper and gets thinner in direct proportion as we proceed up the axis.

Fig.5: A truncated Neiloid which has a rapid taper i.e., gets thinner more rapidly than any of the other three shapes.

The only correct method of finding out the volume will be by immersion of the wood in a liquid. But this is not practicable in forestry.

The next thing is to take a solid having a regular geometrical shape to which the shape and size of the tree approximate. Then to derive the volume of the tree from that of the shape of the solid by applying appropriate formula, after making due allowance for the difference in their shapes.

Hence cylinder has been selected as the regular solid. There will be difference between the cylinder and different shapes of the trees in circumference. The circumference will differ in the stem of a tree as it decreases progressively from the base to the top whereas it is the same in cylinder. Such progressive decrease is called the taper. Hence taper is a measure of the extent of deviation of a tree stem, from being cylindrical. More the deviation, more the taper.

4. METZGER'S THEORY OR GIRDER THEORY: Several theories have been put forward to explain variations in taper from tree to tree and in the same tree. But the most acceptable is that of Metzger, a German Forester. His theory is as follows:

The tree stem should be considered as a cantilever, beam of uniform size against the bending force of the wind. The stem of a tree is built up with the minimum material to resist uniformly to the stresses, to which it is subjected. The wind pressure acts on the crown and is conveyed to the lower parts of the stem in an increasing measure with the increasing length of the bole. Hence the base gets the greatest pressure. Hence the tree may get snapped at the base of the tree. The minimum material is distributed in the stem in such a way that it affords a uniform resistance all along its length. The pressure in the upper part will be less. Hence there will be lesser growth material in the upper part. The pressure gets increased in the lower part. Hence the growth material is also much in the lower part. Pressure of winds on crowns will be changing as the tree is growing in open or crowded portion. Trees growing in open lands or isolation have larger crowns. Hence the pressure exerted on such trees will be the greatest. These trees should allocate most of the growth material on their base for their existence. If these trees allocate more growth material for height, it will be in disadvantage. The pressure will be increased with the increased arm of the lever and there will not be enough material at the base to counteract the force. Only due to this reason, the trees growing in isolation have short and rapidly tapering boles. But the trees growing in crowded portions or dense crops, will have long and cylindrical boles as they are subjected to lesser wind pressure.

5. FACTORS INFLUENCING THE DEGREE OF TAPER: Taper varies from species to species and for the same species growing in varying conditions. The size of the crown is very important single factor

influencing the degree of taper. Bigger the crown, more the taper. Hence these trees growing in isolated places or open areas will have bigger crown and they have more taper than the smaller crowned trees growing in the crowded places of dense forests.

Example: Coconut and palmyrah trees, with the smallest imaginable crowns have the most cylindrical stems.

Difference in manner of tapering: Take conifer growing under 2 different sets of conditions.

Under isolation: They have a larger crown and root system. It will have a pronounced neiloid base (fig.1) central section will be between that of a paraboloid and cone. Top portion will be of a cone.

Under wooded conditions: Small crown - small root system - a short conical top - central section approximating to something mid-way between the frustrum of paraboloid and a cylinder - basal portion to a truncated neiloid.

6. FORM FACTOR: When volume of a tree stem or log is determined, taper of the stem or log has to be considered. When volume of a solid is the product of basal area and height (which represents the volume of a cylinder having the same height and cross sectional area equal to the basal area of the tree), allowance is to be made for the taper by multiplying it with a reducing factor whose value will depend upon the degree of taper which in its turn will change according to the form of the tree. This factor is known as the form factor.

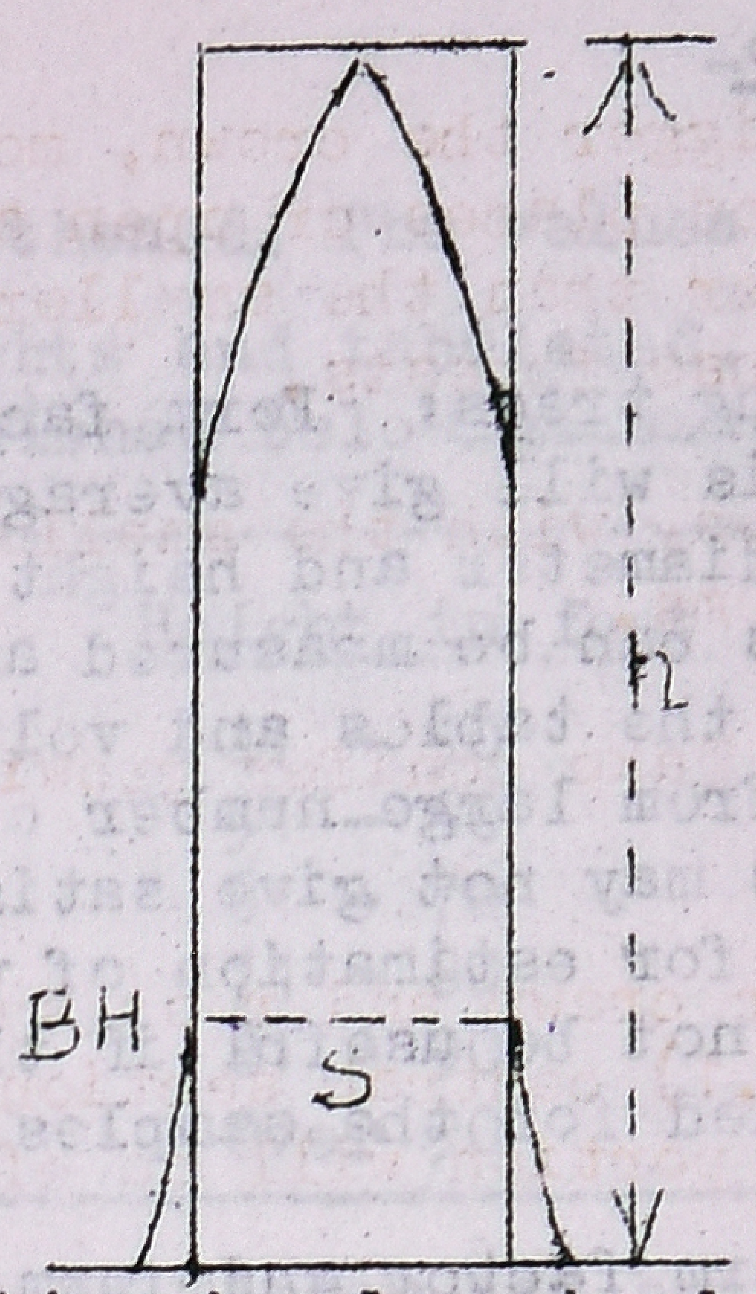
We have already studied that the form of a tree may be cylindrical or paraboloid or conical or neiloid. A paraboloid has 1/2 the volume of a cylinder of the same basal area and height. A cone has 1/3 the volume and a neiloid has 1/4 the volume of cylinder. The difference in shape is expressed by saying that the form factors of a paraboloid, a cone and a neiloid are 0.5, 0.33 and 0.25 respectively. Thus form factor is a factor by which the volume of a tree is compared to the volume of a cylinder with the same basal area and same height.

Definition: Form factor is defined as the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree.

In other words, form factor is the ratio between the volume of a tree to the product of basal area and height. The basal area may be measured in different parts of the tree. Hence the form factors are distinguished in the following classes depending upon the height of measurement of basal area.

ARTIFICIAL FORM FACTOR: This is also known as Breast height Form Factor. In this case, the basal area is measured at breast height. The volume refers to the whole tree - both above and below the point of measurement - please see the figure.

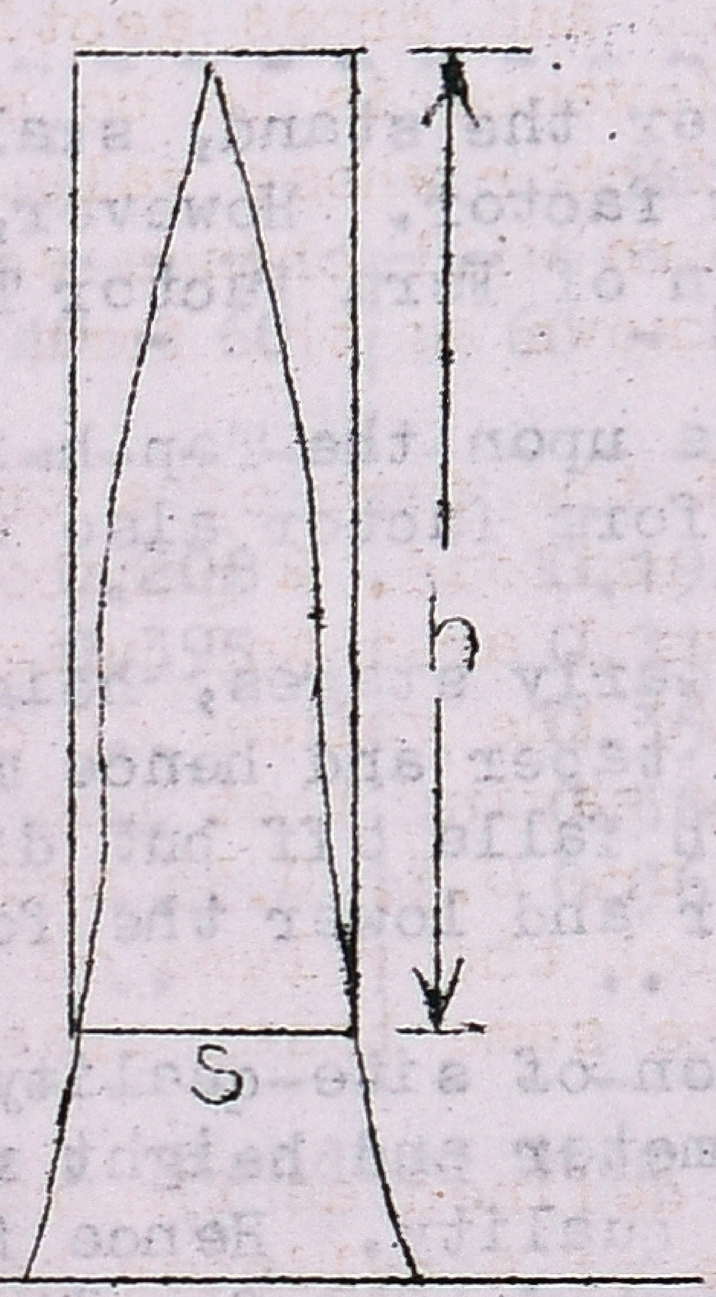
The artificial form factor cannot be taken as a reliable



guide of the tree form. The diameter is taken only at the breast height i.e. a fixed point. We do not bother about the height of the tree. Tree form and tapering always depend upon the height of the trees. Trees of the same form but of different heights will have different form factors. In spite of its unreliability, artificial form factor is universally used. Because,

a) its computation involves handy measurement.
b) Diameter measurement has been standardised to be taken at breast height.
c) This factor is just needed to convert height and breast height sectional area into tree volume.
d) Easy to assess volume of standing trees.

8. Absolute Form Factor: The basal area is measured at any convenient height and the volume refers only to that part of the tree above the point of measurement.



Hence it is the ratio between the volume of the tree above the point of diameter or basal area measurement with the cylinder which has the same basal area and whose height is equal to the height of the trees above that point as shown in the figure. .

9. Normal (or True) Form Factors: Under this, basal area is measured at a constant proportion of the total height of the tree e.g. 1/10th or 1/20th etc. of the total height. The volume refers to the whole tree above the ground level. This form factor has the following disadvantages:

a) height of tree has to be determined before the point of measurement can be fixed.
b) Point of measurement may be very inconveniant in case of very tall as well as very short trees.
c) Factors thus obtained are not as regular as expected.

Absolute and normal form factors are not used. Form factor in India - means only Artificial Form Factor with basal area calculated at breast height. This form factor may be expressed as follows:

$F = \frac{V}{sh}$ where F = Form factor
s = Basal area at breast height
h = is the height of the tree
V = Volume in cubic units.

10. Uses of Form Factor:

1. Estimating volume of standing trees: Form factors may be compiled into tabular statement. This will give average form factor of trees of different dimensions by diameter and height classes. The diameter and height of standing trees can be measured and the corresponding form factor may be read from the tables and volume calculated. Generally these tables are prepared from large number of trees. Hence their application to individual trees may not give satisfactory results. However, these tables will be useful for estimation of volume of a group of trees. Of course, they may not be useful if the conditions vary from the conditions that prevailed for the samples.

2. To study laws of growth: Form factor and form quotient give an insight into the laws of growth, particularly the stem form of trees.

11. VARIABLES AFFECTING FORM FACTOR: The variables affecting form factor are the species, density, site quality, age and height.

i. Species: The sizes of crown differ from species to species. Consequently the form will also vary. Hence form factor has to be determined for each species.

ii. Density of the stand: Denser the stand, smaller the crown, lesser the taper and higher the form factor. However, this is not taken into account in the preparation of Form Factor Tables.

iii. Site Locality: This depends upon the Top height. For the same diameter if the height is more, the form factor also will be more.

iv. Age of the stand: In the early stages, height increases more than the diameter, resulting in less taper and hence more form factor. But after the maturity, height growth falls off but diameter increases, resulting in a higher degree of taper and lower the form factor.

v. Height: It is the reflection of site quality and explained under iii. It may be noted that diameter and height reflect the other variables like density and age, site quality. Hence for practical purposes, form factors are differentiated only for 3 variables i.e. species, diameter and height. Form factor tables are prepared separately for various species based on one variable viz. diameter or height - or 2 variables i.e. diameter and height. When only one variable is used, height is preferred to diameter - because variation in form factor is more with regard to height than diameter.

12. Form factor tables are prepared from data collected from the sample trees felled for the purpose or from records of felled coupes.

i) With Diameter as Variable: Sample trees falling under various diameter classes are felled, measured and volumes and form factors are calculated. The diameters and form factors are then totalled and averaged separately for each diameter class. These averages are then plotted in a graph paper and the curve is smoothened. Form factor values are read for diameters from this curve and tabulated.

ii) With height as a variable: Same procedure is adopted. Sample trees falling under different height classes are felled and volumes and form factors are calculated. Then heights and form factors are totalled separately for different height classes, averaged, plotted

and curve smoothened. The values of form factors are read off for different heights and tabulated. Stem Timber Form Factor Table for Deodar is furnished below as an example:

Height in feet	Form factor
41 - 50	0.17
51 - 60	0.23
61 - 70	0.29
71 - 80	0.32
81 - 90	0.34
Over 90	0.36

Note: Volume of Timber has been calculated by quarter girth formula.

iii) With Diameter and height as variables: Procedure is the same. But separate curves will be drawn for each of the height classes and smoothened over. Form factor values are read off from these curves for the different diameters and tabulated.

Example:

Diameter class at B.H.O.B. in inches	Height data in feet				
	40 - 60	60 - 80	80 - 100	100-120	120-140
8 - 12	0.208	0.194	0.184	0.186	0.303
12 - 16	0.395	0.316	0.281	0.277	0.307
16 - 20	..	0.354	0.310	0.306	0.313
20 - 24	..	0.366	0.320	0.310	0.309
24 - 28	..	0.364	0.325	0.309	0.309
28 - 32	..	..	0.322	0.300	0.306

Note: Above is a Standard Stem Timber Form Factor.

13. Application of Form Factor:

1) They are derived by measurement of a large number of trees. Hence they should be applied only to group of trees. Their application to single tree may not be satisfactory.

2) Their application should be restricted to trees growing under the same conditions (of locality and treatment) as those under which sample trees used in the preparation of the form factor tables, had grown.

14. Form height is defined as the product of the total height of the tree and its form factor. This can be expressed as a formula.

Form Factor F = V/sh
Form height Fh = V/S.

where Fh is Form height V is the volume of a tree; s is the basal area and h is the height of tree.

Form height is used to determine how far it is reasonable to assume that volume is proportional to the basal area. If form height remains constant with increasing diameter, then it is clear that the assumption is justified.

15. Normal Form Quotient: An Austrian Forester, A.Schiffel postulated that taper depends upon the Form Quotient (in 1905). He defined Form Quotient as the ratio between the mid-diameter of a tree and the diameter at breast height i.e.

$$\text{Form Quotient} = \frac{\text{Mid-diameter}}{\text{Diameter at b.h.}}$$

This form quotient is called Normal Form Quotient. But if the height of the tree is 2 x 1.37m height, then the mid point will be the breast height and hence the Form quotient will be one. This will mean that the tree is absolutely cylindrical - which is not true.

16. Absolute Form Quotient: Tor Johnson, a Swedish Forester thought of modifying the concept of the Form quotient. He defined Form quotient as the ratio between the mid-diameter above the breast height and the diameter at breast height.

Form quotient is a device of expressing the Taper. According to Metzer's theory, taper of a tree has to be computed with reference to the shape of the stem devoid of the bark. Hence only under bark measurements should be considered. Hence Absolute Form Quotient is defined as " the ratio of the mid-diameter under bark of the portion of the tree above breast height to its under-bark diameter at breast height ".

Now, Form Quotient means only Absolute Form Quotient as this is much in vogue. It is expressed as a decimal.

17. Form Factor and Form Quotient: Kunze, a German and Clarke, an American forester have shown that for a given tree form quotient is greater than the form factor, by a constant. This constant can always be worked out for the various species. The relationship may be expressed as FQ – C = FF where C is the constant. This constant varies only from species to species. Hence if Form Quotient and C are known Form Factor can be found out. Eg. The constant for some species, as worked out is as follows:

Scotch Pine	=	0.20
Buch	=	0.21 to 0.23

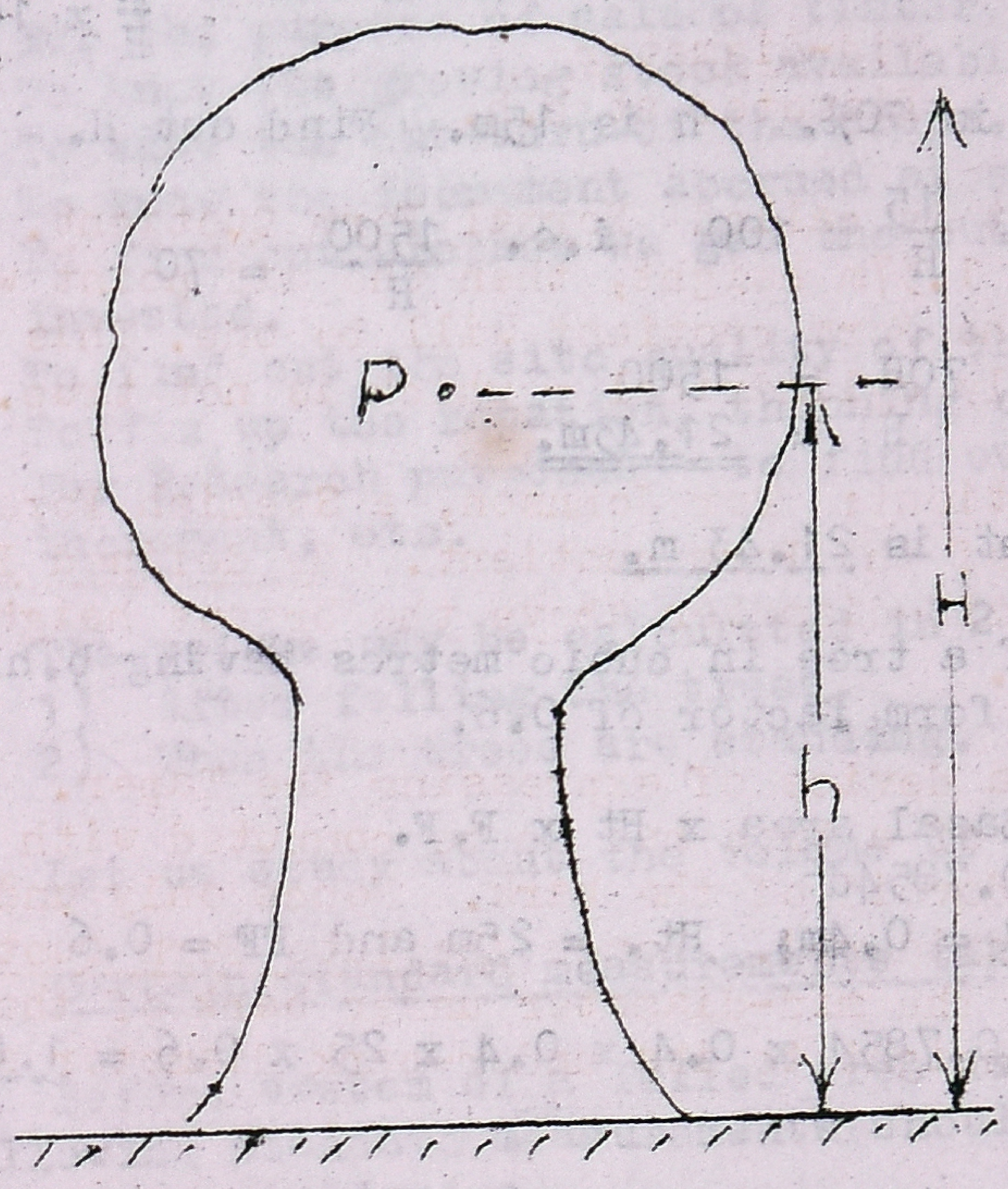
18. Variables affecting Form Quotient: Just like in Form Factor, here also the variables are diameter, height and species. Form quotient tables may be prepared with i) height as the variable ii) diameter as the variable and iii) height and diameter as variables.

19. Form Class: Just as diameter classes, height classes, Form class is a class of tree which have the same form quotients. The trees may be grouped having form quotients differing by 0.05 in value. Eg. 0.50 to 0.55, 0.55 to 0.60, 0.60 to 0.65, 0.65 to 0.70, 0.70 to 0.75 or by the mid point of these values.

20. Use of Form Quotients: They are used

i) in expressing the tapers of the trees
ii) in derivation of form factor after ascertaining the constant and
iii) in preparation of Form classes.

21. FORM POINT RATIO: This was suggested by Tor Johnson to express the tapers of trees.



Form point is the point in the crown of the tree located by ocular means as the centre of wind pressure or the geometrical centre of the crown. Form Point Ratio is the ratio between the height from ground level upto the form point and the total height of the tree - expressed usually as a percentage.

In the figure, P is the Form point, 'h' the height from ground level upto Form point and H the total height. Form Point is

$= \frac{h}{H} \times 100.$

Example: If h is 18m. and H is 20m then Form Point Ratio will be

$\frac{18}{20} \times 100 = 90\%.$

If the tree has a small crown, restricted to the very top of the tree, then h tends to increase. Hence value of Form point Ratio will be much which means decrease of Taper. Imagine Palmirah tree for this.

On the other hand, the tree has a big crown extending far down to the stem (as in the case of tamarind or cashew tree), the value of h will decrease. Form Point Ratio will be less. That means there is more taper.

PROBLEMS

1. The actual volume of a tree having breast height diameter of 50cm and height 40m is 5.5 cubic metres. What is its Form Factor?

Here $S = 0.7854d^2$
$d = 0.5m$
$1 = 40m.$

Hence $0.7854 \times 0.5 \times 0.5 \times 40 \times FF = 5.5$

$$F.F. = \frac{5.5}{0.7854 \times 0.5 \times 0.5 \times 40}$$

$$\text{i.e. } \frac{5.5}{7.85} \quad \text{i.e. } \underline{0.70}$$

The Form Factor is <u>0.70</u>.

2. If a tree having a Form Point Ratio of 70% has its form point located 15m vertically below the top of its crown, what is the total height of the tree? Form Point Ratio = $\frac{h}{H} \times 100$

Form Point Ration is 70%. h is 15m. Find out H.

$$70 = \frac{15}{H} \times 100 \quad \text{i.e. } \frac{1500}{H} = 70$$

$$\text{i.e. } 70H = 1500$$

$$H = \underline{21.43m.}$$

The total height is <u>21.43 m.</u>

3. Find the volume of a tree in cubic metres having b.h.d. of 40cm, height of 25m and form factor of 0.6.

Volume = Basal area x Ht x F.F.
Basal area = $0.7854d^2$
Given = d = 0.4m; Ht. = 25m and FF = 0.6

Hence volume = $0.7854 \times 0.4 \times 0.4 \times 25 \times 0.6 = \underline{1.88m^3}$

Prepare the answers for the following questions:

4. Write a short note on (a) Metzger's Theory (b) Form Factor (c) Form Quotient (d) Form Point Ratio.

5. Define Form Factor, Form Quotient and Form Point Ratio. Bring out the difference between them.

6. What is Form Factor? What are the uses? How would you prepare Form Factor Tables?

CHAPTER V

MEASUREMENT OF VOLUME OF FELLED TREES

1. OBJECTS: The ultimate object of mensurational activity in forest is to estimate the quantity of wood contained in trees and subsequently in crops. Following are the objects of assessing the volume of trees.

i) For the purpose of sale of timber or small timber or fuel.
ii) To know the growing stock available in the forest.
iii) To know the out-turn of the crops.
iv) To know the increment accrued at specified periods.
v) To find out whether we get the out-turn for the capital invested.
vi) To find out the site quality of the area.
vii) To fix up the rotation, thinning cycle, etc. of plantations.
viii) For Research purposes - to find out the rate of growth, rate of increment, etc.

The volume may be calculated in 2 ways.
1) After felling the trees.
2) When the trees are standing.

Let us study about the volume of felled trees in this Chapter.

2. Certain standard measurements taken prior to conversion:

Before a stem of a felled tree is taken up for conversion, the following standard measurements should be taken up for the purpose of record and statistics.

a) Crown length is the length of the stem from its tip to a point midway between the point where lowest green branch has originated and the point from where a whorl of green branches have started growing alround the stem.

b) Crown width is the maximum spread of the crown expressed at widest diameter.

c) Clear or clean Bole: is defined as part of the stem which extends from the ground level upto a point on the stem, which is midway between the points of origin of the lowest green branch and a whorl of green branches forming a green crown alround. Crown length deducted from the total height of the tree gives the length of the clear bole.

d) Merchantable Bole or Commercial Bole is the length of the bole that is ordinarily fit for utilisation as timber. Hence it consists of that part of the stem which extends from the butt to the point upto which the wood of the stem is utilizable.

e) Standard Stem Timber is the timber of the stem of a tree from ground level to the point on the stem where the average diameter over bark is 20cm. Its volume is calculated on full basal area but exclusive of bark.

f) Standard small wood is the timber of the stem of a tree between the limiting diameters of 20cm and 5 cm over bark. Its volume is calculated on full basal area but it includes the bark.

g) Standard branch timber is the timber from the branches of a tree down to 20cm diameter over bark. Its volume is also calculated on full basal area but exclusive of the bark.

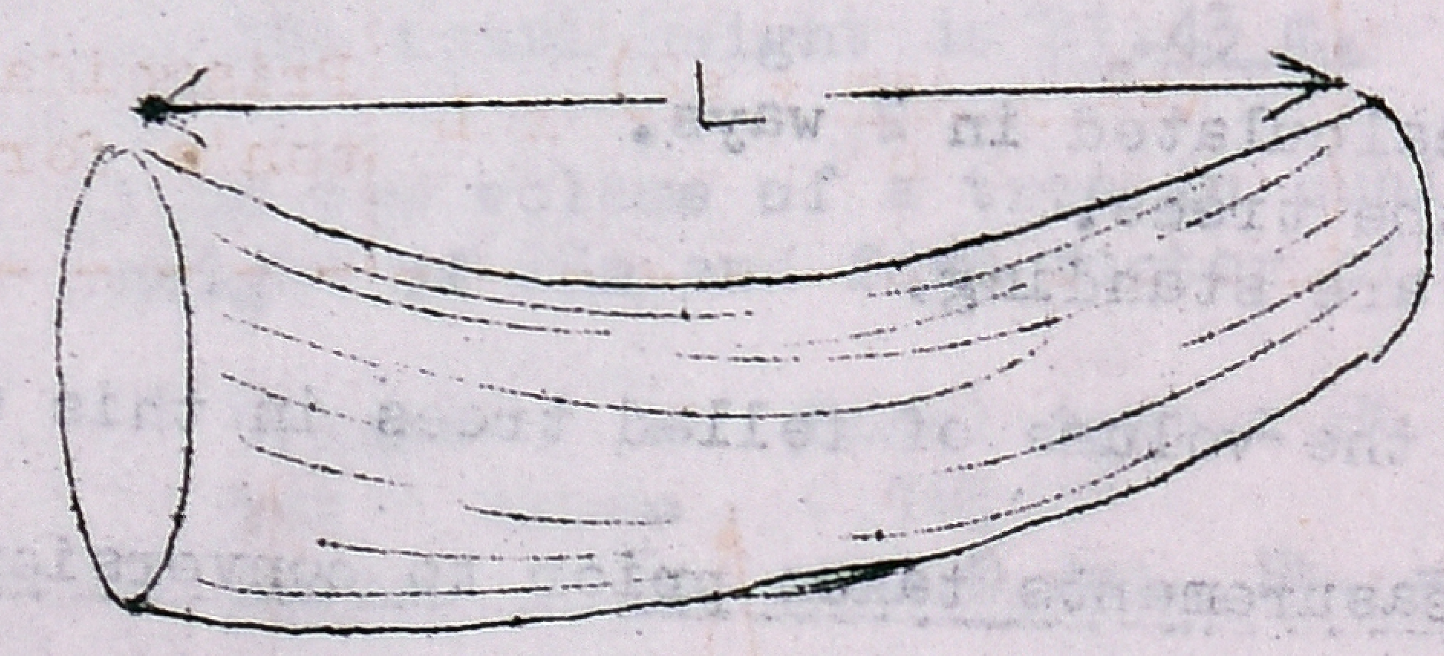
h) Standard branch small wood is the timber from the branches of tree between the limiting diameters of 20cm and 5cm over bark. Its volume is calculated on full basal area inclusive of its bark.

i) Other measurements: Diameters or girths over bark and under bark at mid height as well as at the mid point between the breast height mark and the tip are also taken.

Measurement of Stem wood: Stemwood is measured normally after converting them into several logs. Method of cross-cutting will be explained later.

3. How measurements are taken:

a) Length: Length of logs are measured straight from end to end without giving any allowance for the curvature of the stem. If the butt end has been shaped with the axe, the projecting end, if any should be excluded from the length. It is measured correct to a decimeter.



b) Diameter or Girth: Diameter and Girth measurements are taken both over bark and under bark at either the mid point of the log or at either end - depending upon whether Huber's or Smallion's formula will be used for determination of their volumes.

For measuring the diameter or girth under bark, a strip of bark is removed alround the circumference of the log at the point of measurement.

4. Volume of Felled Trees: This consists of volume of stemwood, branch wood and root wood (when it is uprooted and valuable as in the case of sandalwood). But stem forms the maximum volume of a tree. We have already seen how the measurements should be taken.

5. Cross cutting Trees into Logs: Trees taper irregularly. The more irregular is the taper of the stem, greater will be the number of logs into which it will have to be divided. But it should also depend upon requirements in market. Following guidelines may be followed:

i) The volume of the log depends upon the thinned logs. Hence logs will be cross-cut depending upon the rate of taper. More the tapering, less will be the length of the log.

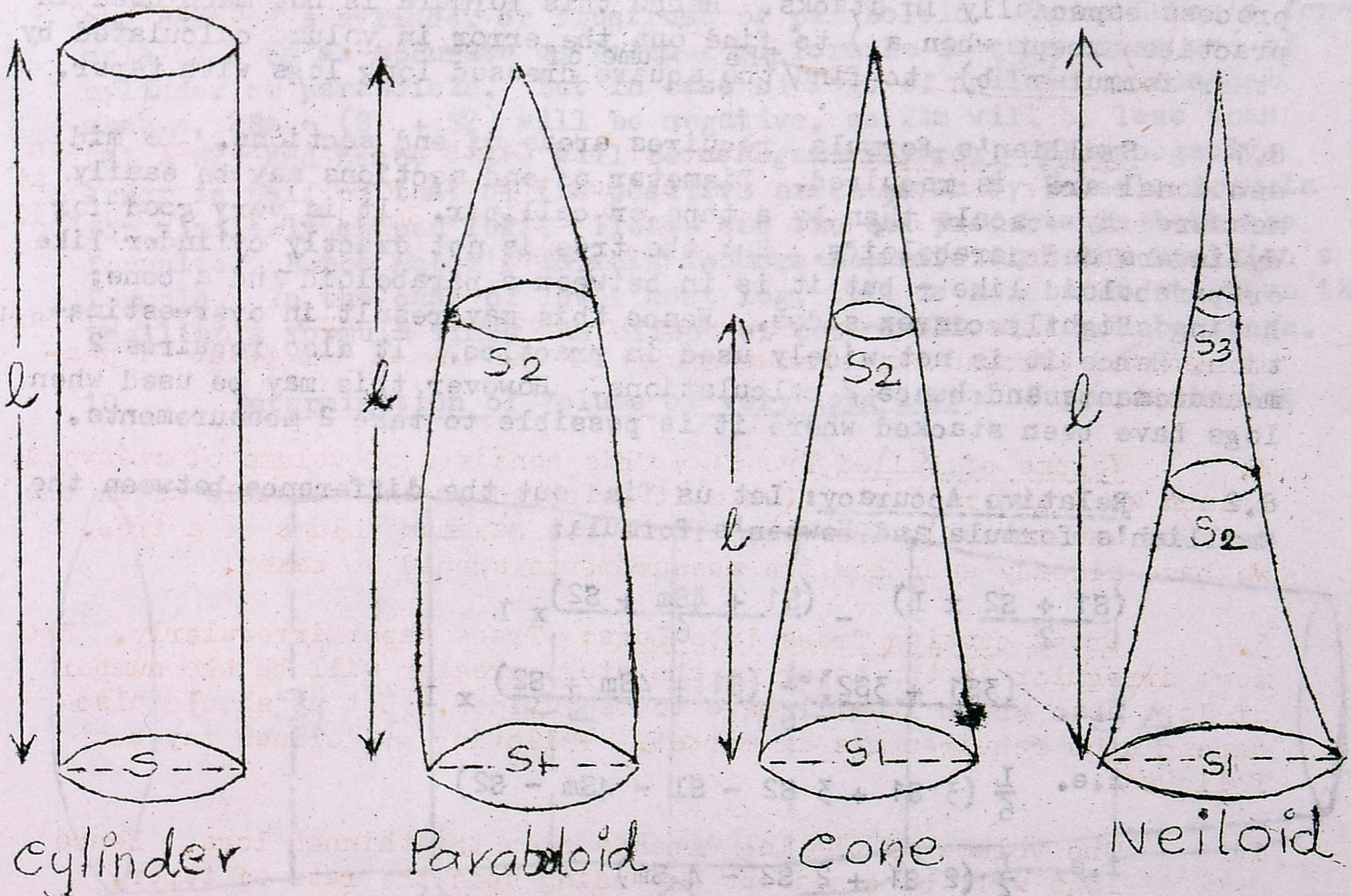
ii) Sometimes, higher rate may be got for longer lengths of timber. Ex. Poles. In such cases it may be cut in longer lengths.

iii) The log should be transportable easily from the forests. Carts can transport logs, of longer length - but not lorries. Hence length of log may be less than 4.5m when transported by lorries.

iv) For Research work, logs are of generally of 3m. Only in the top ends it may be upto 4.5m. If the topmost end is more than 1.5m it is cut separately as a section.

6. Calculation of Volume of Logs: Following table gives the volumes of 3 types of logs, compared with the cylinder.

Form of solid	Volume of full solid	Volume of a frustrum of solid	Remarks
1) Cylinder	SL	SL.	..
2) Paraboloid	$\frac{SL}{2}$	i) $\frac{s1 + s2}{2} \times L$	Smallian's formula
		ii) sm x L	Huber's formula
3) Cone	$\frac{SL}{3}$	$\frac{s1 + s2 \sqrt{s1s2} \times L}{3}$	..
4) Neiloid	$\frac{sL}{4}$	$\frac{(s1 + 4sm + s2)}{6} \times L$	Prismoidal or Newton's formula.



FORMULAE USED

i) Prismoidal or Newton's formula : $V = \frac{(s1 + 4sm + s2)}{6} \times L$

ii) Smallian's formula : $V = \frac{s1 + s2}{2} \times L$

iii) Huber's formula : $V = sm \times L$

where V = volume of the log;
s = sectional area at the base.
s1 = sectional area at thick end
sm = sectional area at middle
s2 = sectional area at the thin end
and L = length of the log.

ANALYSIS OF EACH FORMULA

7. Prismoidal or Newton's formula: is the most accurate one, as it gives the volume of neiloid, cone, cylinder and paraboloid shapes. But it involves measurement of diameter or girth at 3 places i.e. thin end, thick end and at middle portions. Hence it is a tedious process especially in stacks. Hence this formula is not much used in practice except when a) to find out the error in volume calculated by other formulae b) to find the volume of the square dressed long logs with taper.

8.1 Smallian's formula requires areas of end sections. No mid sectional are is required. Diameter of end sections may be easily measured by a scale than by a tape or calliper. It is very good for cylinders and paraboloids. But the tree is not exactly cylinder like or paraboloid like - but it is in between a paraboloid and a cone; having slightly convex sides. Hence this may result in over-estimation. Hence it is not widely used in practice. It also requires 2 measurements and hence 2 calculations. However this may be used when logs have been stacked where it is possible to take 2 measurements.

8.2 Relative Accuracy: Let us find out the difference between the Smallian's formula and Newton's formula:

$$\left(\frac{S1 + S2}{2} \times L\right) - \frac{(S1 + 4Sm + S2)}{6} \times L$$

i.e. $$\frac{(3S1 + 3S2) - (S1 + 4Sm + S2)}{6} \times L$$

i.e. $$\frac{L}{6}(3\ S1 + 3\ S2 - S1 - 4Sm - S2)$$

i.e. $$\frac{L}{6}(2\ S1 + 2\ S2 - 4\ Sm)$$

i.e. $$\frac{L}{3}(S1 + S2 - 2\ Sm)$$

In the case of trees of cylindrical shape or frustrum of paraboloid s1 will be equal to s2. Hence s1 + s2 will be 2Sm. In such case the difference will be zero and hence Smallian's formula will be equal to Prismoidal formula. But in the case of cone or neiloid, S1 + S2 will be greater than 2Sm and hence Smallian's formula gives positive error.

9.1 Huber's Formula: This requires measurement of mid-sectional area only. This may not be possible when the logs have been stacked without incurring extra expenditure, for separating them. But it is more accurate and involves only one measurement and hence convenient to use in case of logs lying singly. This formula is generally used for calculation of standard timber and standard smallwood, and in all scientific investigations. However this formula is used only next to Quarter Girth formula.

9.2 Relative Accuracy:

Huber's formula and Prismoidal formula

$$(Sm \times L) - \frac{(S1 + 4Sm + S2)}{6} L$$

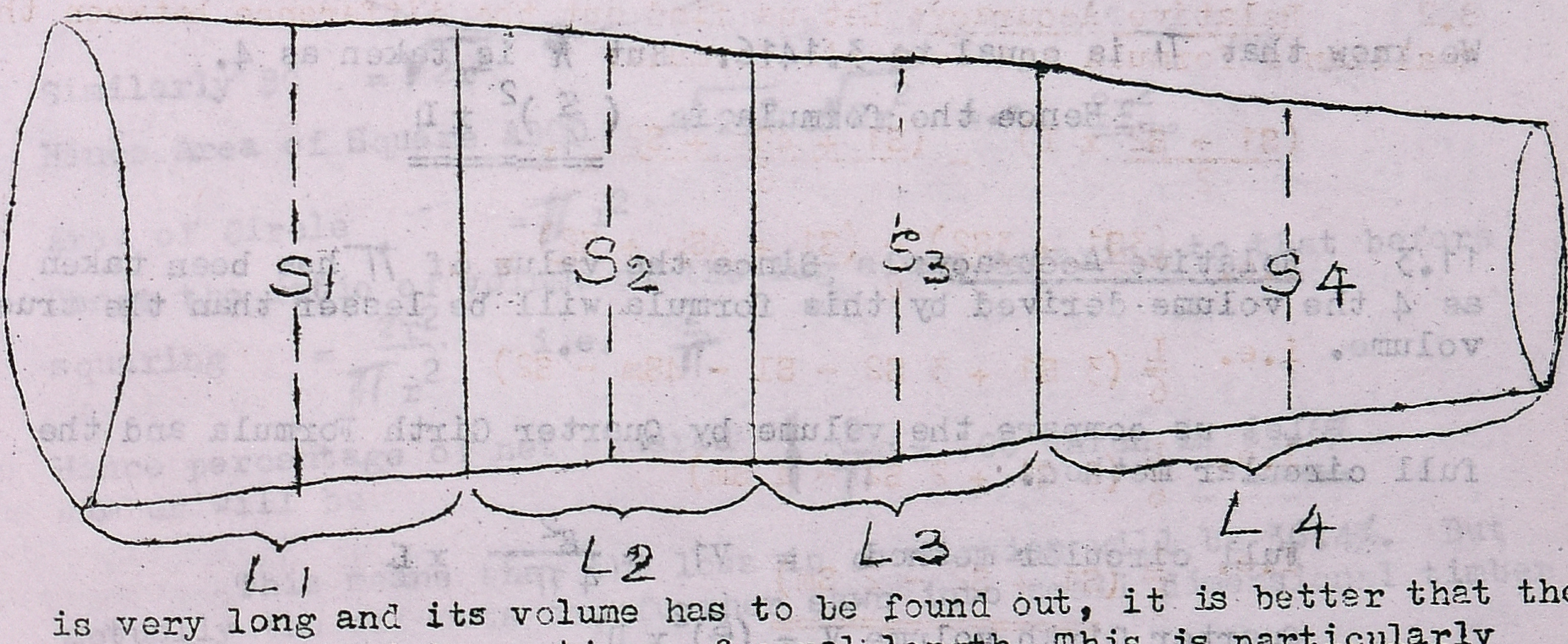
i.e. $\frac{L}{6}$ (6 Sm - S1 - 4 Sm - S2)

i.e. $\frac{L}{6}$ (2 Sm - S1 - S2)

i.e. $\frac{L}{6}$ (2Sm - (S 1 + S2)

Here also, if S1 = S2, then S1 + S2 will become 2sm and hence there will be no difference between the two. But this will be only in the case of a cylinder or frustrums of paraboloid. Hence Huber's formula will be as accurate as Prismoidal formula in case trees are of cylinder or paraboloid. But in case of logs of neiloid or conical shapes, 2Sm - (S1 + S2) will be negative, as 2Sm will be less than (S1 + S2) and hence there will be a negative error. This negative error is half of that of the positive error given by Huber's formula for similarly shaped logs. Please see the end products in both the formulae. Hence Huber's formula is more accurate than the Smallian's formula. In the case of lower most log, this is more accurate than the Smallian's formula since the effect of root-swell will not be there.

10. Determination of Volume of very long logs: Suppose the log



is very long and its volume has to be found out, it is better that the log is divided into sections of equal length. This is particularly adopted when the log is lacking in straightness and uniformity of taper. The volume of each section may be calculated by Huber's or Smallian's formula and added to get the total volume of the log.

Let the log be divided into 4 sections. Let mid sectional area and length of sections be S1, S2, S3, S4 and L1, L2, L3 and L4 respectively. The volume of each section will be

1st section S1 x L1;
2nd section S2 x L2
3rd section S3 x L3
4th section S4 x L4

Total volume will be S1L1 x S2L2 x S3L3 x S4L4.

If length of each section is uniform - say L, the volume of log will be L (S1 + S2 + S3 + S4).

11.1 Quarter Girth Formula:

Volume of log is $\left(\frac{g}{4}\right)^2 \times L$

where g is the girth of the log at middle and
L is the length of the log.

This formula is widely used in Great Britain, Burma and India for determining the volume of logs. This is also known as Hoppus Rule in Britain after the name of Hoppus who has prepared the tables for use with it.

11.2 Derivation:

$$\text{Volume} = \pi r^2 L; \quad \text{But } g = 2\pi r$$

$$\text{Hence } r = \frac{g}{2\pi}$$

Now substitute $\frac{g}{2\pi}$ for r

$$\text{volume} = \pi \times \frac{g}{2\pi} \times \frac{g}{2\pi} \times L$$

$$\text{i.e. } \frac{g^2}{4\pi} \times L$$

We know that π is equal to 3.1416. But π is taken as 4.

$$\text{Hence the formula is } \left(\frac{g}{4}\right)^2 \times L$$

11.3 Relative Accuracy: Since the value of π has been taken as 4 the volume derived by this formula will be lesser than the true volume.

Let us compare the volume by Quarter Girth Formula and the full circular method.

$$\text{Full circular method} = V1 = \frac{g^2}{4\pi} \times L$$

$$\text{Quarter Girth volume } V = \left(\frac{g}{4}\right)^2 \times L$$

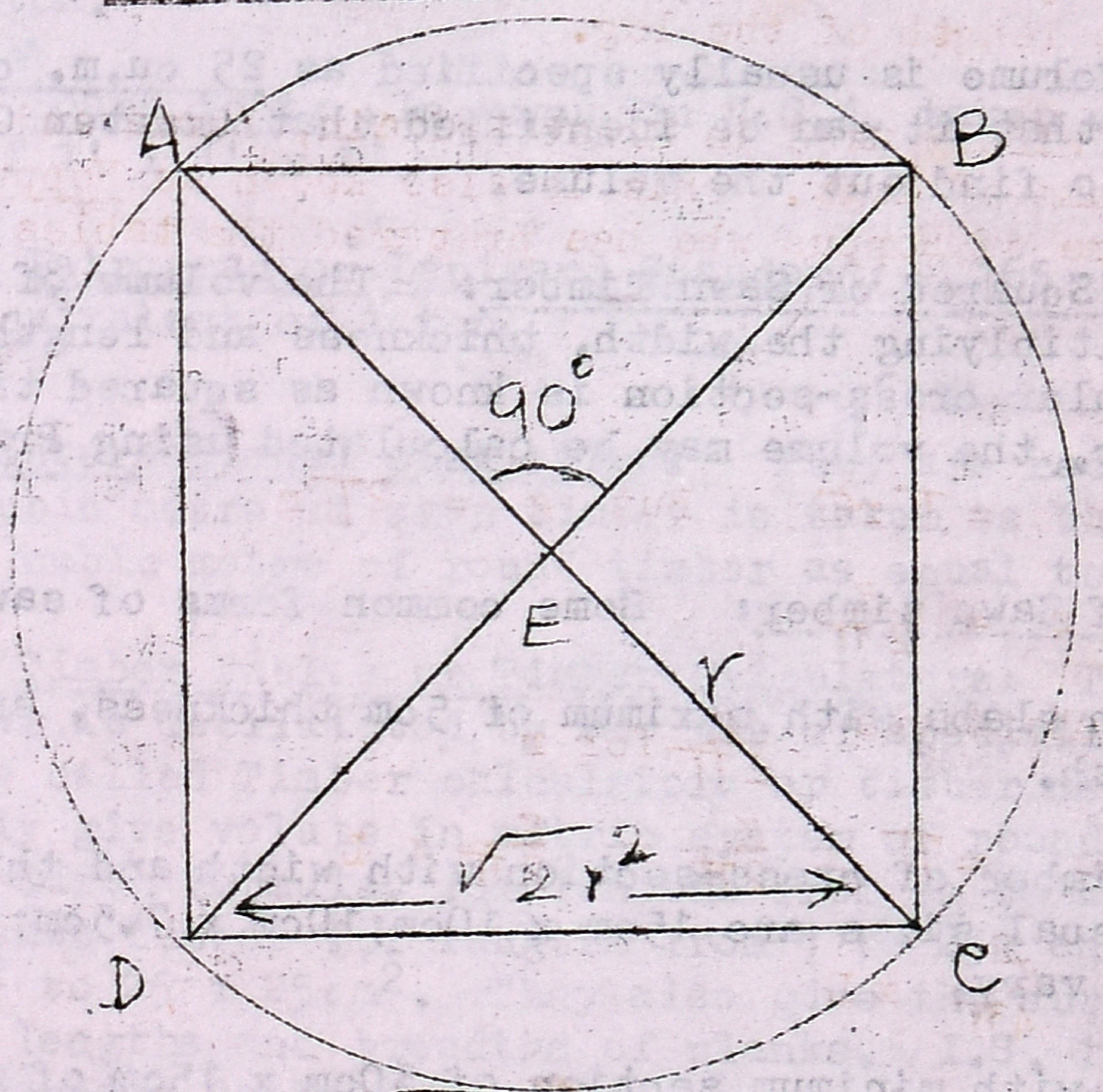
$$\text{Thus } \frac{V}{V1} = \frac{\left(\frac{g}{4}\right)^2 \times L}{\frac{g^2}{4\pi} \times L}$$

$$\text{i.e. } \frac{g}{4} \times \frac{g}{4} \times L \times \frac{4\pi}{g^2} \times \frac{L}{L}$$

$$\text{i.e. } \frac{\pi}{4} \quad \text{i.e. } \frac{3.14}{4} \quad \text{i.e. } 0.785 \text{ or } 78.5\%$$

11.4 Why Quarter Girth? When a log is measured in the forest, the girth is taken under bark. But the round logs are actually squared, before converting them into scantlings. Hence full circular measurements cannot represent the marketable volume of the logs as there would be loss of wastage when squaring a round log. In order to assess the squared timber, contained in a log, quarter girth is used. The shortage of 21.5% were supposed to cover this loss.

11.5 What is the loss? The Quarter Girth formula cannot give the exact volume as only mid-girth is taken. It is the thin end of the log that decides the actual quantity of timber.



The circular log has a radius of r. The square within the circle represents the square portion.

Area of the square $= AB \times BC$

$\angle AEB = 90°$

Hence $AB = \sqrt{AE^2 + BE^2}$

$= \sqrt{r^2 + r^2}$

$= \sqrt{2r^2}$

Similarly $BC = \sqrt{2r^2}$

Hence Area of Square ABCD $= \sqrt{2r^2} \times \sqrt{2r^2}$ i.e. $2r^2$

Area of Circle $= \pi r^2$

Hence the ratio of volume of the log after squaring to that before squaring $= \frac{2r^2}{\pi r^2}$ i.e. $\frac{2}{\pi}$

Hence percentage of net squared timber will be $\frac{2}{\pi} \times 100$ which is 63.6%.

This means that the loss in conversion will be 36.4%. But actually the off-cuts are further sawn into small dimensional timber to improve recovery.

11.6 Application of Quarter Girth Formula: Though this formula under-estimates the volume of the round log by 21.5%, it is most widely used formula in practice due to the following reasons.

i) It is applied mostly for girths taken over bark. The bark

content of logs is estimated to be 20 to 25%, on an average. Hence, it gives the true timber contents of the logs.

ii) It is simple to use.

iii) It has been in use for a long time, and it has become customary to use only this formula. All those who deal with timber have become used to the implications of application of this formula.

iv) Logs are not truly circular in cross-section. The volume determined on the assumption that they are truly circular is greater than the real volume. This formula helps to counteract this error.

11.7 Suggestion: At present I.S.I. standards for purchase of timber by Defence, Railways, etc. specify calculation of volume by Quarter Girth formula only. This involves lot of loss of money to the Forest Corporation and Forest Department. It is suggested that in future, true circular volume should be adopted instead of Quarter Girth Formula, so that there will not be further financial loss to the Forest Department.

Quarter Girth volume is usually specified as 25 cu.m. q.g. or simply $25 m^3$ Hoppus so that it can be identified that Quarter Girth formula has been used to find out the volume.

12.1 Measurement of Squared or Sawn Timber: The volume of sawn timber may be found out by multiplying the width, thickness and length. Timber with square or rectangular cross-section is known as squared timber. If the timber has taper, the volume may be calculated using Prismoidal formula.

12.2 Common forms of Sawn timber: Some common forms of sawn timber:

i) Planks: Wooden slabs with maximum of 5cm thickness, and of varying width and length.

ii) Scantlings: Timber of cross-section with width and thickness not exceeding 15cm. Usual sizes are 15cm x 10cm; 10cm x 7.5cm; 5cm x 5cm - length may vary.

iii) Beams: Timber with minimum section of 30cm x 15cm of varying lengths.

iv) Blocks or boxes or squares: Timber of short lengths like 60 to 120 cms with square cross-sections.

Eg. 120 cms long and 30 x 30cms size.
90 cms long and 25 x 25cms size.

v) Railway sleepers: Following are the various categories of Railway sleepers as fixed by the Railway Board:

Category	Approximate No.per km.	Dimensions in cm	Volume in m^3 of one Number.
Broad gauges	1191	275 x 25 x 13	0.08938
Metre gauges	1210	180 x 20 x 11	0.03960
Narrow gauges	1250	150 x 18 x 11	0.0297

12.3 Sawing into Planks: When timber is sawn into planks, sawing charges are paid on the basis of superficial area of sawn surfaces.

For example if a log of 10 metres long is sawn into 4 planks of 40cm width, 6 planks of 30cm width and 3 planks of 20cm width, sawing charges will be paid for a superficial area of

$$\frac{4 \times 10 \times 40}{100} + \frac{6 \times 10 \times 30}{100} + \frac{3 \times 10 \times 20}{100}$$

i.e. 16 + 18 + 6 i.e. 40 Sq. metres.

12.4 Other units of measure:

1. Shipping standard: 50 Cft. of timber is taken as equivalent to one ton.

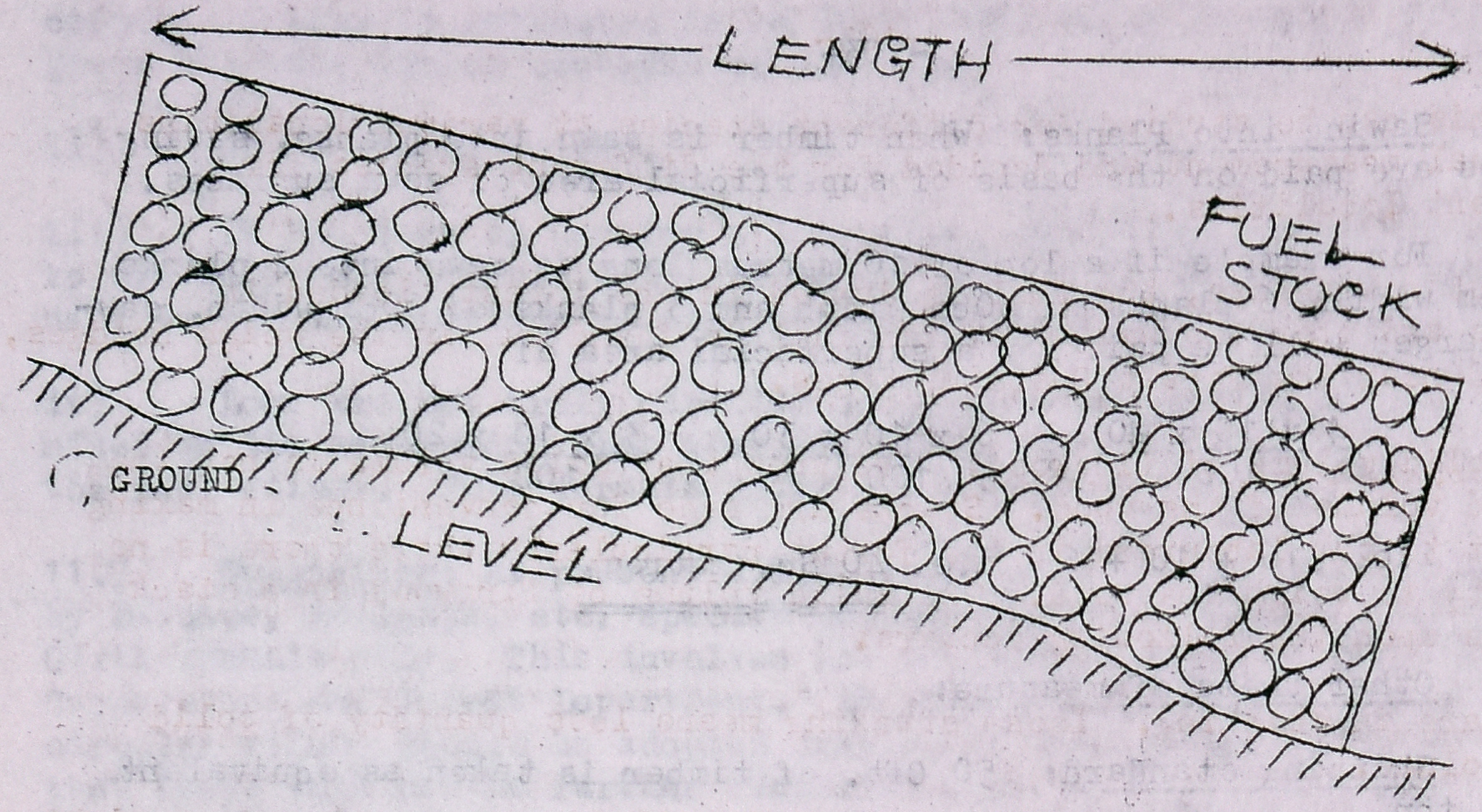
2. Board foot: In vogue in U.S.A. taken equivalent of volume of board of 1' x 1' x 1".

3. Petrograd or Lepigard Standard: 165 cft. of sawn softwood taken equivalent of 1 ton.

4. International statistics: They are recorded in cubic metres and 1 cubic metre of sawn timber is taken as the equivalent of 35.313cft. and one cubic metre of round timber as equal to 27.735 Hoppus foot.

13. Timber Tables or Timber Calculators: The measurement of volume of timber is facilitated by the use of specially prepared timber tables. They are called Timber calculators or timber measurement tables. They generally give volume in metric system of round timber calculated by Quarter Girth Formula, for lengths from 1m to 25m and girths upto 90cm and of sawn timber for lengths from 1 to 25m and cross section from $1 \times 1cm^2$ to $25 \times 25cm^2$. They also give the surface area sawn for various lengths and breadths of planks. I.S. 1020 - 1957 Indian Standard Conversion Table for ordinary use give useful tables in metric system. Forest mensuration conversion tables published by the F.R.I. & Colleges, Dehra Dun give area of circles from 1cm to 120cms and cubic contents for diameter of logs from 1 to 120cms and length of logs for 1 to 9 metres.

14.1 Measurement of Branchwood: Except for some thick branches which are sawn, other branches were left in the forest itself. But as the population increased, there was a demand for fuel. Hence nothing is left in the field. Even the twigs as in the case of Casuarina, has got a marketable value as fuel. Due to the development of good transport facilities, everything marketable is transported easily in lorries; mostly the branch wood is used only as fuel. It is not possible to measure the volume of each piece of branch, called the billet. It is usual to stock the billets in a particular form of rectangular parallelo-pipeds and calculate the cubical contents of the stack. Hence only the space occupied by the fuel wood is measured and not the fuel itself. Hence it is called " Stack volume " which is defined as the space occupied by a stack. This is not the volume of wood i.e. solid volume. When the stack is built on sloping ground, its length is measured horizontally and not along the slope. as shown in the figure.



The volume of the stack is calculated by multiplying the length, breadth and height of the stack.

14.2 Size: The size of the fuel stacks varies from place to place. The depth of the stack from front to rear is usually equal to the length of the billets. In olden days, in U.P., the stack was of 7.2m (24 feet) x 1.8m (6 feet) x 1.5m (5feet). If it was not possible to put such long stacks, they were halved i.e. 3.6m x 1.8m x 1.5m. In Dehra Dun Division it was smaller i.e. 1.8m x 1.0m x 1m.

14.3 Cord: The term Cord is often used to express the volume of stacked wood. The size of the cord varies in different countries. The American cord contained 128 cft. (stacked 4' x 8' x4'). In India and parts of England a cord may measure 12' x 6' x 3', containing 216 cft. In India it is some times 100 cft. (5' x 4' x 5'). This changes from place to place. In U.P., a stack is of 24' x 6' x 5' i.e. 720 cft. Hence the dimension has to be mentioned when mentioning a cord of stacked wood.

14.4 Allowance in stacking: Fuel is usually stacked immediately after cutting - when it is in green. But the sale is conducted at a later date, either by volume or by weight. There will be shrinkage and loss of weight due to dryage which is due to evaporation of moisture and rotting of bark and thinner parts of the fuel. Hence, an allowance was often made for this by reducing the height of the stack on the basis of experience. Thus a 6' stack may be counted as if only 5' high. Such deduction was given for careless stacking or loose stacking. Lohani studied the loss of weight on dryage for some species and found that the loss was usually 40 to 50% for most of the species under study. Quercus incana showed only 20 to 30% of loss whereas Rhododendrum arboreum lost more than 50%. This loss depended upon the period of storage as well as the species. For example Quercus lost moisture upto 75% and 90% in 177 and 276 days respectively while the same percentage of loss in the case of Rhododendron, took place in 154 and 217 days respectively. Jeyaraman has reported that freshly stacked fuel of Eucalyptus globulus measuring 2.5m x 1.5m x 1m may weigh as much as 2174 kg. in green condition and on drying it weighs only 1812 kg. - the dryage loss being about 17%.

This can be studied for different species at various localities by actual measurement and decided for the different species for different localities.

But now-a-days, the fuel is dumped in the forest, loaded in lorries and then the weight of the fuel is found out in the weigh bridges, located near the Forest Checking gates.

15.1 Solid volume of firewood: We know that solid volume is not the stacked volume of the wood. Stacks are made for convenience in making payment to the labourers in the forest particularly where there is no facility to weigh the wood. The solid volume of firewood in a stack depends upon the following factors:

1. Care in stacking. Loose stacking means less quantity of solid volume.
2. Form of billets: If the individual billets are smooth and straight, the amount of solid volume will be greater than the crooked, bent billets with rough bark.
3. Split billets cannot be packed as closely as round regular billets.
4. Length of the billets; shorter billets pack better than longer billets.
5. Diameter of billets. A stack of large billets contains proportionately greater solid volume than a stack of small billets.

Hence unless and until stacking is done properly, accurate estimation of volume of stacked wood will be very difficult.

15.2 Stacking Rules: Following rules should be observed while stacking:

1. Keep conifer wood separate from hard wood.
2. Keep split billets separate from round billets.
3. Keep all the billets of the same length in one stack.
4. Keep the billets of more or less same diameter in one stack.

15.3 Conversion or Reducing Factor: Reducing factors are factors by which the stacked volume is multiplied to get the solid volume. This gives the relationship between the solid volume and stacked volume. This is determined by experimental basis and then it is used in the routine manner. This is also called conversion factor. The correct factor depends upon the method of stacking. The percentage of solid wood in a stack varies from 55% to 80%. Following are some of the conversion factors based on experiments:

$$\text{Conversion factor} = \frac{\text{Solid volume}}{\text{Stacked volume}}$$

, usually expressed in decimals.

Species	Diameter class of material	Reducing factor
Conifer	Large round straight poles.	0.80
"	Medium split billets smooth and straight	0.75
"	Medium split billets crooked	0.70
"	Small round firewood	0.70
Hardwood	Large split billets smooth or straight	0.70
"	Large split billets crooked	0.65
"	Small round firewood smooth and straight	0.65
"	Small round firewood crooked.	0.55
Small branches & twigs	..	0.35-0.45
Brushwood	..	0.15-0.20

Solid volume/Stacked volume:

Chirpine .. 0.46 Ranikhet Division, U.P.

Oaks .. 0.50 Ranikhet Division and Chakrata Division, U.P.

Weight/Stacked volume:

Oaks .. 5.76 quintals per cubic metre stacked in Chakrata Division, U.P.

Other species .. 3.48 quintals per cubic metre stacked, Chakrata Division, U.P.

Eucalyptus globulus (Nilgiris) : 100 cft. of stacked volume will be of 1.5 tonnes.

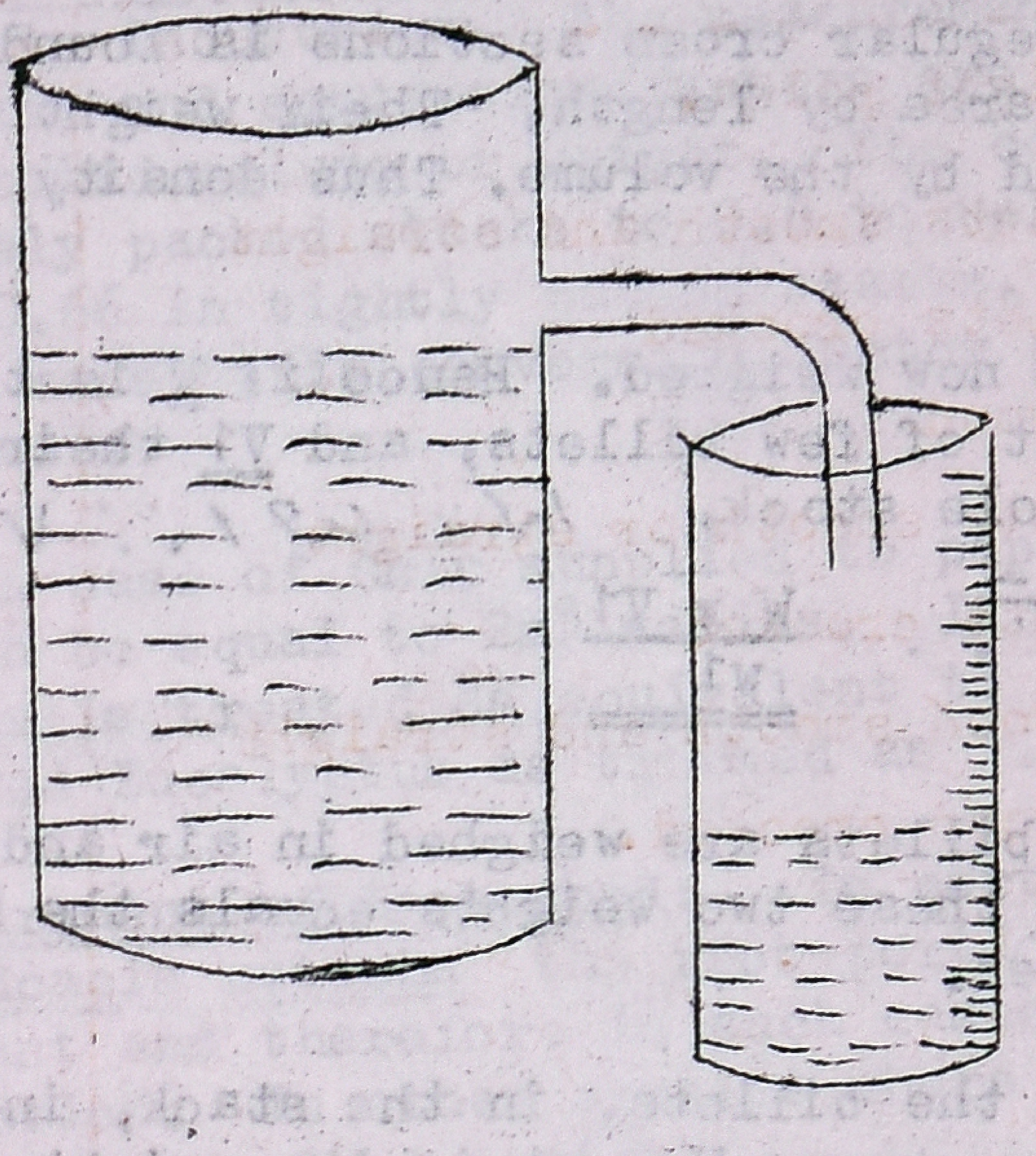
$2m^3$ = 1.1 tonnes.

16. Methods of determination of solid contents: Following methods can be adopted:

1. Xylometric method
2. Volumetric method
3. Hydrostatic method
4. Specific gravity method.

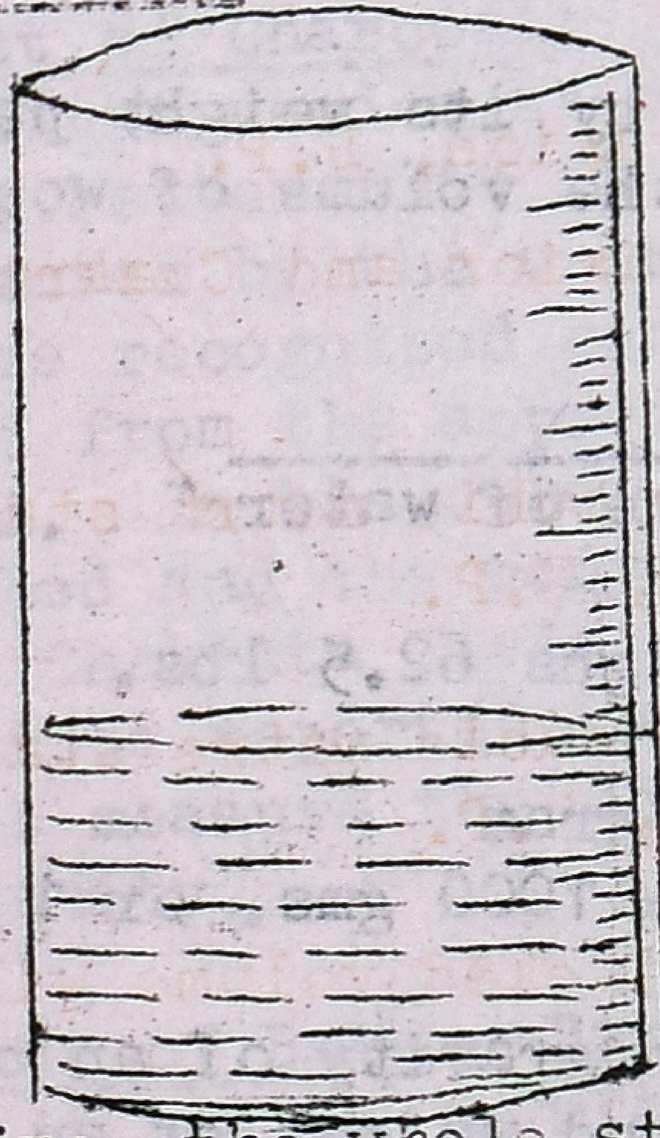
16.1 Xylometric method: The volume of billets can be calculated with the help of a xylometer. Xylometer consists of a water container in which the wood can be submerged. The water container is graduated or has a graduated scale. Volume is calculated by the principle of water displacement. Water is poured in the vessel and reading of water level is taken. Then the pieces of wood is submerged and the reading is again taken. Then the difference between the two readings give the volume of pieces of wood submerged.

a) Karl Heiver's method: In some cases the vessel has got an overflow pipe from which the water overflows into a second graduated



vessel. In this case the vessel is filled upto the overflow pipe. When the wood is submerged the overflow is collected in a graduated vessel and its volume measured. Volume is calculated on the principle that a submerged body displaces its own volume of water. Care should be taken to see that the wood is not kept in the water long to prevent the possibility of its absorbing water.

b) Reising's method: This method is similar to the above method. Here the vessel will have a vertical scale on its side. Levels are read before immersion of billets and afterwards. The difference in level multiplied by the cross-sectional area of the tank will give the solid volume of wood in the stack.



To save time, the whole stack is first weighed and only a small portion is submerged, which is also weighed. The volume of small portion is calculated. As the volume is proportional to weight, the volume of the whole stack can be calculated from that of the portion submerged.

Let W be the weight of whole stack of wood and w be the weight of submerged pieces, V the volume of the former and v that of the latter. Then W : w :: V : v.

$$\text{Hence } Wv = wV; \quad \text{Hence } V = \frac{W \times v}{w}.$$

This method is however cumbersome and hence not much used in practice. But this is good to find the volume of irregularly shaped billets.

16.2 Volumetric method:

a) The mid girth or diameter of each billet has to be measured and the sectional areas calculated, totalled and multiplied by the length of the billets. This can be expressed by the formula

$$V = 1\ (S1 + S2 + S3 + \ldots\ldots\ldots Sn)$$

where V = solid volume of the stack.

S1, S2, S3, etc. mid sectional area of the billets.

1 = length of the billets.

b) The second method is based on the principle that

$$\frac{\text{weight}}{\text{Density}} = \text{volume.}$$

The volume of a few billets of regular cross sections is found out by multiplying their mid-sectional area by length. Their weight is also measured. This weight is divided by the volume. Thus density is found out.

The whole stack of fuel is now weighed. Hence if W is the weight of the whole stack, w1 the weight of few billets, and V1 their volume and V the solid volume of the whole stock, W : w1 :: V : V1

W V1 = w1 V ∴ V =

$$\frac{W \times V1}{w1}$$

16.3 Hydrostatic method: The billets are weighed in air and later in water. The difference between these two weights equals the weight of equal volume of water displaced.

If w is the weight of all the billets, in the stack, in air, and w1 is the weight of them in water, then, W - w1 is the weight of an equal volume of water.

Weight of volume of water divided by its weight per unit volume gives the volume of water and therefore the volume of wood. Hence the volume of wood V will be

$$V = \frac{w - w1}{\text{weight of unit volume of water}}$$

British unit: 1 cft. of water weighs 62.5 lbs.

Metric system: 1 cubic c.m. = 1 gram
1 cubic decimetre = 1000 gms. or 1 kg.

16.4 Specific Gravity method: Specific gravity of an object can be defined as the ratio between its weight and weight of an equal volume of water. According to the principle of Archimedes, if an object is immersed in water, it suffers an apparent loss of weight, which is equivalent to the weight of the water displaced, as explained above.

Hence if specific gravity of wood is known, then the volume can be calculated from the weight of the billet.

$$\text{Specific gravity of a piece of wood} = \frac{\text{Weight of wood}}{\text{Weight of the same volume of water}} = \frac{\text{Density of wood}}{\text{Density of water}}$$

As density of pure water is 1 gram per c.c., the density of wood in grams per c.c. is the same as its specific gravity minus the units.

$$\text{Volume} = \frac{\text{Weight in gms}}{\text{Sp. gravity}} \text{ cc}$$

$$\text{In F.P.S. system, Volume} = \frac{\text{Weight in Lbs.}}{\text{Sp. Gr.} \times 62.5} \text{ Cft.}$$

17. Measurement of Pulpwood: Of late, lot of pulpwood is supplied to various pulp industries. The measurement of pulpwood is usually made in stacks; and conversion factors are used to convert the stacked volume into solid volume or weight. The conversion factors vary from 0.3 for loosely packed stacks to 0.8 to well packed stacks. It is between 0.5 to 0.66 in tightly packed stacks. Whenever large scale supplies are made, this conversion factor should find place in the agreement itself.

In the case of Chir supplied to paper mills in U.P., $3m^3$ stack is treated to be equal to $2m^3$ solids. In Karnataka, $2m^3$ stacked wood of Eucalyptus is treated as equivalent to one tonne. In Tamilnadu, $2m^3$ of stacked Eucalyptus is treated as 1.1 tonne.

18. Measurement of Root wood: In certain species like *Santalum album* and *Acacia catachu* the root-portion of the tree is commercially very important and therefore in such cases, it is weighed carefully after extraction. In other species where the roots are used as fuel, it is stacked and sold by weight.

19. Measurement of Charcoal: Charcoal is sold either by weight or by volume. The weight varies so enormously with the humidity of the air. Hence it is better that it is measured by volume. The volume of charcoal is estimated by the volume of charcoal kiln or by volume of wood-burnt by some recognized conversion factor. The volume of kiln may be calculated from the approximate shape of the kiln. This is not a reliable method. In the other method, the firewood to be burnt as charcoal is weighed and the conversion factor gives the volume/weight of charcoal. In Chakrata Division of U.P., 6 quintals of oak or miscellaneous firewood is reported to yield one quintal of charcoal. The best method is to measure the charcoal with a tin or basket or wooden box of known capacity.

20. Measurement of Bark: Bark is valuable in certain species like wattles. Hence it has to be measured. The volume and weight of bark varies greatly with the species, age of the tree and the amount of drying to which the bark has been exposed. Usually young trees have higher percentage of bark volume. Generally bark is sold only on weight basis in Nilgiris Division in the case of wattle bark. Bark yield tables giving weight of wattle bark has been prepared for Nilgiris Division. Bark volume table for *Acacia nylotica* has been prepared by Chaturvedi.

PROBLEMS

1. Find the volume of log of following dimensions by a) Quarter Girth formula b) Huber's formula, c) Smallian's formula and d) Prismoidal formula.

i) Length of log	= 30m.	ii) Diameter at thin end	= 20cm.
iii) Diameter at thick end	= 30cm.	iv) Diameter at mid point	= 25cm.

Let us find the sectional area.

Sectional area $= \pi r^2$; But $r = \frac{d}{2}$

Hence $s = \pi \times \frac{d}{2} \times \frac{d}{2}$ i.e. $\frac{3.1416}{4} d^2$ i.e. $0.7854d^2$

$S1 = 0.7854 \times \frac{20}{100} \times \frac{20}{100}$ i.e. $0.7854 \times 0.2 \times 0.2$

i.e. $0.03 m^2$

$S2 = 0.7854 \times 0.3 \times 0.3$ i.e. $0.07 m^2$

$Sm = 0.7854 \times 0.25 \times 0.25$ i.e. $0.05 m^2$

Let us find out the Girth also, for middle portion.

Girth = $2\pi r$

Mid diameter is 25cm Hence r = 12.5cm.

$G = 2 \times 3.1416 \times 12.5$ i.e. 25×3.1416 i.e. 78.54 cm.

a) Quarter Girth Formula:

$$V = \left(\frac{g}{4}\right)^2 \times l$$

i.e. $\frac{78.54}{4 \times 100} \times \frac{78.54}{4 \times 100} \times 30$ i.e. $1.16 m^3$

b) Huber's formula:

$V = Sm \times l$ i.e. $0.05 \times 30 = 1.5 m^3$

c) Smallian's formula:

$V = \frac{S1 + S2}{2} \times l$ i.e. $\frac{0.03 + 0.07}{2} \times 30 = 1.5 m^3$

d) Prismoidal formula:

$V = \frac{S1 + 4Sm + S2}{6} \times l$ i.e. $\frac{0.03 + (4 \times 0.05) + 0.07}{6} \times 30$

i.e. $1.5 m^3$

2. If Reducing factor of a given species of wood is 0.625, and if the solid volume is $12.5 m^3$, what is the stacked volume?

Solid volume = Stacked vol. x R.F.

$12.5 m^3 = V \times 0.625$ $V = \frac{12.5}{0.625}$ i.e. $20 m^3$

Stacked volume will be $20 m^3$.

Prepare the answers for following questions.

3. Mention the 3 formulae used for calculating volume of logs. compare the relative accuracy between them.

4. Mention Quarter Girth Formula. Derive it. What is the relative accuracy when compared with a circular formula? Why is it commonly used?

5. Explain i) stacked volume ii) solid volume iii) Reducing Factor.

6. How will you measure the volume of fire wood? Mention atleast 3 methods.

CHAPTER VI

MEASUREMENT OF VOLUME OF STANDING TREES

1. Object:

i) To assess the growing stock and to fore-cast and regulate the yield, i.e., for the purpose of management.

ii) For the purpose of sale; i.e. for evaluating standing timber earmarked for sale by estimating its volume.

iii) For purpose of research. Ex. Determining volume of trees in a sample plot.

2. Methods: Following methods are used for finding out the volume of standing trees. The choice of a particular method depends on the circumstances of the case - especially the purpose for which measurements are going to be made use of.

2.1 Ocular Estimate: Experienced persons can make fairly accurate estimate of volume of standing trees marked for felling by careful inspection on the basis of records of past fellings. But this is too subjective for reliable results. Different persons may produce different results. Even the same persons may estimate differently depending upon their moods - say when they are tired, hungry, etc. This gives error even to the tune of 25% in some cases. However, every forest officer must train his eyes to make a fair estimate of the volume of standing trees. For this the estimator requires much of practice and ample opportunity to compare his ocular estimate with the actuals, after the trees are felled.

2.2 Partly ocular and partly by measurement: Under this method, usually diameter is measured, the basal area calculated and this is multiplied by height and form factor. Height is measured and Form factor is assumed depending upon the nature of taper. Here scope of error is much less than the ocular estimate. This method also requires lot of experience and practice. Otherwise the estimates may not be correct.

2.3 Direct measurement: In this method, diameters and heights of trees are actually measured in sections (as in the case of a felled tree) by sending a man up the tree. But this method is time consuming and tiring and cannot be used when large number of trees are involved.

2.4 By the use of form factor tables: These tables will give form factors for various heights. The diameter and height are measured. The form factor for the height is found out from the tables. Volume may be obtained by the formula

$$V = Bh\ f \text{ where}$$

V is the volume;
B is the Basal area;
h is the height and
f is the form factor.

3. By the use of Volume Tables:

3.1 Definition: Volume Table is a table showing for a given species the average (cubical) contents of trees, logs, or sawn timber for one or more given dimensions. The dimensions may be i) d.b.h. alone ii) d.b.h. and height, iii) d.b.h., height and some measure of form or taper.

In other words, a volume table is a tabular statement giving the average volume of trees of a given species by girth, diameter, height or form classes.

3.2 Object: To estimate the volume of an average tree of known dimensions and thus to estimate the volume of a given crop or marked trees in a coupe.

3.3 Applicability: These tables are based on actual measurements of sufficiently large number of trees. They are prepared on the assumption that the trees of the same species with the same dimensions will have the same value. Hence the scope of applicability depends upon the sources of the measurements, on which the averages given in the volume table are taken. Hence, before using a volume table it is necessary to see if the table is applicable to the particular locality where it is being used. The volume table may not give the exact volume of an individual tree as the volume of the individual trees may be different from the average based on several individuals. Hence the volume table can be applied only to a group of trees, like coupes - but not to individual trees.

3.4 Why Volume Table? We can easily find out the volume of individual trees by actual measurements of the trees. But it is a laborious and time consuming process, especially when there are hundreds of trees in a coupe. But volume table gives us the average volumes of individual trees as well as group of trees that stand in a coupe. It may not be so accurate. But it is found to be good enough for our Forest Management purposes.

3.5 Variables: The volume of a tree depends upon

i) diameter
ii) height and
iii) form and sometimes on
iv) site quality.

The choice of variable or variables on which to base the tables, depends upon i) the extent of their intended applications, ii) simplicity, iii) speed with which they have to be applied, with desired accuracy.

For a restricted area, only one variable (e.g.) diameter may serve the purpose. In small areas trees of the same diameter can be expected to have the same height and same form, and hence the same volume.

In larger areas, at least two variables will have to be considered i.e. diameter and height. Of course, volume tables with single variable is easy to use. More than one variable complicates the use of the table and requires more time for taking measurements and preparation of volume table. But, volume tables with one variable are not so accurate in larger areas as trees of the same diameter may not have the same heights or forms. Hence for larger areas,

volume tables should be prepared based on 2 variables of height and diameter.

Volume tables can also be prepared with three variables, i.e. diameter, height and form. This is more accurate. But it is involving three measurements and hence laborious to prepare and use the table. The advantages of volume table i.e. ease and simplicity will not be there.

Diameter at breast height is the most important of these variables. Next to this comes the height and last of them is the form. An error of 10% in diameter results in a greater error in volume than a similar error in height or form as the error in diameter measurement gets squared at the time of calculating the sectional area. Hence if volume table is to be based on single variable, d.b.h. should be the only variable not only to avoid the error but also for easy measurements, since it is easy to measure the d.b.h. of trees.

CLASSIFICATION OF VOLUME TABLES:

4.1 The volume tables can be classified in three ways; viz.

i) According to the number of variables on which they are based.

ii) According to their scope of application.

iii) According to the kind of out-turn given by them.

i) Classification according to the number of variables:

4.2 a) Volume Tables based on one variable viz.diameter alone:

In this, the trees are classified by d.b.h. (o.b.) only. But it is very difficult to take the individual diameter of trees. Hence, usually diameter classes are used. Hence these tables show average volumes of trees by diameter classes.

Since heights of trees will not be the same for the diameter in different localities, such volume tables cannot be used for extensive areas. They can be used only locally - hence they are called Local Volume Table. These are easy and quick to use as they require the measurement of only d.b.h. (o.b.).

ii) Volume Tables based in two variables i.e. diameter and height:

Trees of same diameter may have different heights and hence different volumes in some localities. In such cases this type of volume tables are prepared and used. This can be used for larger areas. The volumes can be read for different diameter classes and height classes pertaining to the total height of the trees. Some times height classes of merchantable boles are used instead of total height.

As total height is the index of the site quality also, these volume tables give volume for diameter classes and site quality also, provided the quality classes for the species have been differentiated. In such cases, the volume tables are based on 2 variables i.e. diameter and site quality, as well as diameter and height.

iii) Volume Tables based on three variables: These are based on diameter, height and form quotient; such tables are the most accurate. But they are expensive and difficult to prepare and inconvenient and time consuming in their application. Hence such tables are not prepared in India but prepared in Sweden and England.

4.3 Classification on the basis of scope of application:

i) General Volume Tables: This is designed to cover the whole natural range and dimensions of a species. It is intended to be applied for a large geographical area covering the entire habidat of the species. They are usually based on two variables i.e., d.b.h. and tree total height. These tables show volumes of trees by diameter classes and in each diameter class by height classes. As they are prepared, from a wider range, they have a limited direct application. They are mostly used for deriving the local volume tables. They cannot give accurate figures for particular localities. There are several kinds of General Volume Tables depending on the kind of the volume they show: (Eg.) Standard Volume Table, Commercial Volume Table, Sawn out-turn Table, Assortment Tables, etc. about which we will study under, para 4.5.

ii) Regional Volume Table: These are compiled from measurement of trees growing in a region. Hence they have a limited application. They are prepared only for a particular tract or region and hence applied only for that. They are based on 2 variables i.e. d.b.h. and height. It is more or less similar to General Volume Tables but they are applicable to a smaller area.

A specimen of Regional Volume Table for U.P.Sal (Stem Timber only) is furnished below. Everything down to 8" diameter over bark is considered as Timber.

	Volume in cubic feet			
Height class / Diameter class	41' - 60'	61' - 80'	81' - 100'	101' - 120'
Just over 8"-12"	4	8	11.5	..
" 12"-16"	14	21	28	35
" 16"-20"	29	39	50	61
" 20"-24"	47	63	80	95.5
" 24"-28"	..	95	118.5	139.5
" 28"-32"	..	135	165	192

Note: Above Table gives volume in the round of stem timber only i.e., Timber obtained from the stem down to a limiting diameter of 8" over bark.

Example:

Suppose the classified abstract of the data collected from the enumeration of a forest block shows the following:

Diameter class	Height class	No. of Trees
12" - 16"	41' - 60'	50
12" - 16"	61' - 80'	20
16" - 20"	61' - 80'	40
20" - 24"	81' - 100'	10

Total volume of stem timber according to the above table will be,

50 x 14	= 700 Cft.	20 x 21	= 420 Cft.
40 x 39	= 1560 Cft.	10 x 80	= 800 Cft.

Total: 3480 Cft.

4.4 iii) Local Volume Tables: These volume tables are compiled from the measurement of trees growing in restricted locality, i.e. a coupe, compartment, etc. They are generally based on one variable only - i.e. d.b.h. (o.b.). They are therefore applicable only for one locality i.e. coupe or compartment since the assumption that the trees of the same diameter will have the same height will hold good for such small areas. These tables are used for a) estimating the volume of standing trees before felling with the object of regulating yield in accordance with working plan prescriptions or b) for making confidential estimate of the volume of the coupe.

These can be prepared either directly from the data collected or from the General Volume Tables by graphical method.

4.5 Classification on the basis of kind of out-turn:

i) Standard Volume Table: These tables give the estimated out-turn of standard timber i.e., from the ground level to the limit of the portion of the tree stem or branch where diameter is 20cm measured overbark and small wood i.e., the volume between the diameter limits of 20cm and 5 cm both measured over bark. The volume gives in terms of round timber which includes volume of stump. It is calculated on full basal area basis from over bark diameters. But Standard Stem timber excludes the volume of bark while standard small wood includes it. This is mainly used as a basis for reference.

ii) Commercial Volume Tables: In this, contents of round timber is given as volume measured down to a thin end diameter to which conversions is done. The stump volume is omitted. The diameter level of conversion may change from time to time and place to place. Hence scope of applicability of this tables is limited. The market requirements decide the minimum limit of exploitation. Hence this tables may be unfit. The chief use of this tables is to serve as a basis for preparation of local and usually temporary tables for individual coupes.

iii) Sawn out-turn Tables: In this, contents of sawn timbers are given as volume measured down to a thin end diameter to which conversion is done, the stump volume being omitted. Hence these are similar to Commercial Volume Tables except for the fact that these give volume of sawn timber instead of volume in round.

iv) Assortment Tables: This gives the volume in round - down to various stated thin end diameters - say 25cm, 20cm, 15cm. Thus the standard volume table and commercial volume tables are special cases of assortment tables.

v) Sawn-out-turn Assortment Tables: These are similar to assortment tables. They give sawn out-turn in the number of standardized pieces instead of volume in round.

5. Information available by Volume Tables: The volume tables give the following information.

i) Name of species (both common and scientific) and its distribution.

ii) Basic data i.e., the locality from which the data were collected and the number of trees measured for compilation of table together with any work done to collect information such as increment borings, stem analysis, stump analysis, etc.

iii) The method of compilation and computation i.e., the method of measuring sample trees; whether according to the standard procedure or by some other method upto certain diameter limits; whether the method of computation was according to the standard procedure or some other methods; the checks applied, etc.

iv) Mathematical equations, if fitted to the basic data.

v) Applicability.

vi) Volume of trees by diameter classes and height classes if two variables have been used, in the form of tabular form. This is the main table.

It also gives the following further tables.

a) Table of basic averages.

b) Table of individual and aggregate checks.

c) Table for underbark volume.

d) Table for Bark thickness/bark percentage.

e) Other tables such as diameter-growth table, commercial volume table (if the main volume table is for standard timber), and conversion factors, etc.

6. Method of preparation of Volume Table: The volume tables can be prepared by the following methods:

i) Graphical method
ii) Regression equations method or the method of least squares fit.
iii) Alignment chart method.

First method is the most commonly used one. Hence, we shall study only the first method.

7. Graphical method of preparation of general Volume Tables:

Steps to be taken:

i) Selection of felled trees.
ii) Measurements of each tree.
iii) Computation of volume of each tree.
iv) Classification of tree volumes according to diameter and height classes.
v) Averaging the volumes of each separate diameter and height classes.
vi) Elimination of irregularities in final table by graphic plotting and curves.

7.1 i) Selection of Trees:

a) Trees of typical height and development and form evenly distributed over the range of type or quality class concerned in the area to which the results are to be applied, should be selected.

b) Trees with defects other than those that are common to the species e.g., fork, broken top, etc. are not selected.

c) Separate sets of trees should be selected to represent different origins, different thinning techniques, etc.

d) Trees above the average are not selected.

e) Sufficient number of trees representing the complete range of diameter and height classes should be selected.

f) A small number of trees, suitably selected, gives better result than a larger number of trees with improper selection. Hence care must be taken to select the trees.

g) The number of trees required depends upon the i) grouping adopted, ii) the precision required and iii) the deviation of individual tree volumes from the mean in each group. In India 1000 trees covering the whole range of diameters and heights is considered satisfactory. In Germany, 40000 trees have been selected.

7.2 ii) Measurements:

Measurements vary with the kind of General Volume Table to be compiled.

A) Standard Volume Table: For this,

i) diameter at breast height over and under bark.
ii) Total height to the nearest whole decimetre
iii) Standard timber bole, i.e., the length of stem from ground level upto a point where the average diameter over bark is 20cms, measurement being taken in a straight line and not along curves or bends. In the case of forked trees, if forking takes place below breast height i.e. 1.37m, each fork has to be taken as a separate tree. If forked below the crown, larger arm should be treated as stem and the volume of the other should be separately recorded as branchwood.

iv) Standard Timber i.e. volume of the timber including that of the stump - but excluding bark down to a limiting diameter of 20cms. over bark covering both stem and branches.

v) Standard Smallwood volume including bark between the limiting diameters of 20cms. and 5cms. over bark.

vi) The standard practice for measuring timber and small wood volumes of a felled tree is to divide the total length into sections of 3 metres length, odd length being included in the last sections, which should not exceed 4.5m, and taking the underbark and overbark diameters at the mid points of such sections. The sections are to be measured straight without giving any allowance for curvature, hollowness, defects, etc. except as additional data, when specially so required.

Standard timber and small wood volume of branches should be measured and recorded separately - when required.

vii) Diameter over and underbark at a point mid way between the breast height and top of the tree.

viii) If species exhibit annual rings, ring count on the stump and the height of the cut pith above ground level on the uphill side, are also recorded.

ix) An estimate of the quality of the locality on any accessable standard is also recorded.

Generally, even when the object is only to prepare commercial volume tables, particulars regarding standard volumes are also recorded.

B) For Commercial Volume Tables:

i) Diameter overbark at breast height.

ii) Total height to the nearest whole decimetre.

iii) Commercial timber boles i.e., the length of the stem as far as the wood is utilised, or to any limit accepted for the purpose.

iv) Commercial timber i.e., volume excluding bark from the butt as far as the wood is utilised or to any limit accepted for the purpose.

This can be measured by dividing the commercial timbe bole into as many equal sections as possible (not exceeding 6m in length) and taking the measurements of each section i.e. length of each section and diameter underbark at mid point of sections.

Ordinarily, trees forking below 4m height should not be measured. But when such trees are taken the procedure indicated under " Standard Timber " should be followed.

v) Diameter over and under bark at the middle of the commercial bole.

Recording: The data of the individual trees should be summarised and finally grouped into height and diameter classes in a table, called the Table of basic averages - a specimen of which is given below:

Diameter classes in cm.	Height classes in metre								
	5.1 - 10.0 M			10.1 - 15.0 M			15.1 - 20.0 & so on		
	Dia (cm)	Ht (m)	Vol (m^3)	Dia (cm)	Ht (m)	Vol (m^3)	Dia (cm)	Ht (m)	Vol (m^3)
0 - 4	3	6	..	2.5	12	..	2.8	16	..
	2	7	..	3.5	11	..	3.4	17	..
	3.5	8	..	3.8	14	..	3.6	17	..
	3.6	9	..	3.9	12	..	3.8	16	..
	3.8	9	..	3.9	14	..	3.6	18	..
Total	15.9	39	..	17.6	63	..	17.2	84	..
Average	3.2 cm	7.8 m	..	3.54	12.6	..	3.44	16.8	..

7.3 iii) <u>Computation of volume of each tree:</u> Volume of each section is calculated by multiplying the mid-cross sectional area as read from the sectional area tables with length.

7.4 iv) <u>Classification of Tree volumes according to Diameter and Height classes.</u>

Following diameter and height intervals can be conveniently adopted for classification of height and diameter classes.

a) For trees measuring 50cms diameter at breast height and over at maturity. : 10 cms.

b) For trees measuring 30cms. d.b.h. and over at maturity. : 5 cms.

c) For trees measuring below 30cms. d.b.h. at maturity. : 2 cms.

d) For trees attaining 25m. or more height at maturity. : 5 M.

e) For trees attaining less than 25m. height at maturity. : 3 M.

7.5 v) <u>Elimination of irregularities in final tables by graphic plotting and curves:</u>

A. <u>Graphic plotting of data and its advantages:</u> In graphing, the variables whose values are known are shown along the horizontal axis or "x" axis and the dependent variables i.e., the variables whose values is to be sought (eg) volume in the case of volume table - is shown in "y" axis or vertical axis or the ordinates. The scales should be so chosen that the average slope of the resulting curve should be more or less 45°. With steep sloping curve, it is very difficult to read independent variable accurately. The slope may be flattened by increasing the scale of the "x" axis or steepened by decreasing it. Graphic method of portraying data has the following advantages.

i) Every measurement taken influences the whole series of results instead of the figure in its own class.

ii) Inconstituencies or inaccuracies in measurement are more easily detected.

iii) Where data is incomplete, intermediate values, and in some cases, values outside the limits of the data available, can be obtained from a graph. The curve renders possible the interpretation of missing data, but it is unsafe to extend it to cover values beyond the limits of the original data.

iv) The use of the curves enables the investigator to obtain a given degree of accuracy with a greatly reduced number of field measurements.

7.6 B) <u>Application of Graphic method to construction of Volume Tables:</u>

There are 3 variables in the construction of General Volume Tables. Volume is the dependent variable. Diameter and height are the independent variables. We know that only 2 values can be plotted in a single curve. The volume of tree varies with diameter and height. But variations due to height cannot be shown in the same curve, with those due to diameter. Hence curves can be drawn showing the relationship between the diameter and volume separately for each height class. Each curve may be named after the height class in question. These constitute the first set of curves.

Similarly, curves can be drawn showing the relationship between height and volumes for a given diameter classes. These constitute the 2nd set of curves.

Values read from these curves are again plotted against mid-diameter intervals. These constitute the final curves from which values are read and tabulated as Volume Tables.

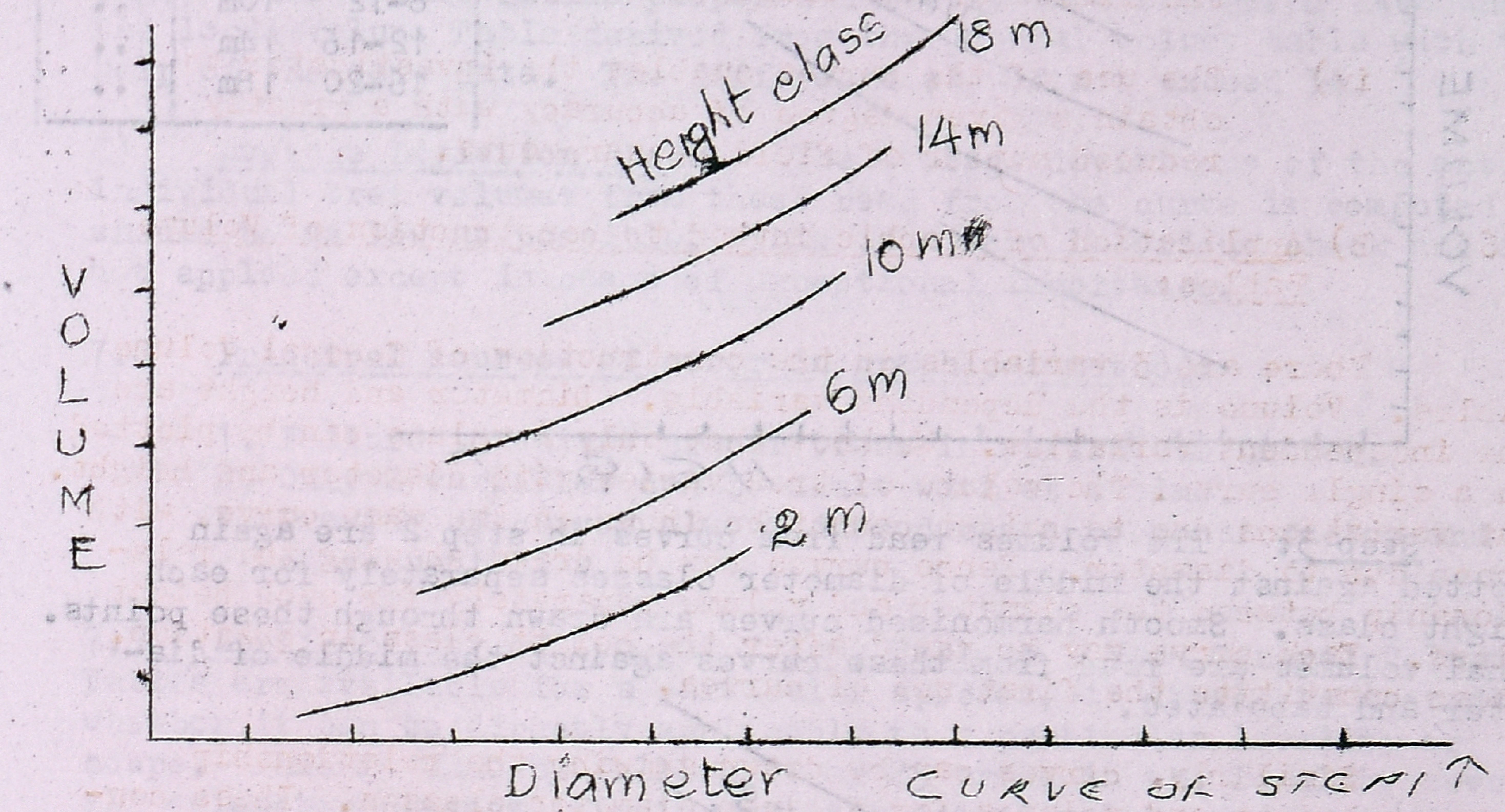
C) <u>Curves:</u> The values recorded in the table of basic averages by diameter and heights are then plotted in the following three successive steps and smooth curves are drawn.

<u>Step 1:</u> Average diameter is plotted against corresponding average volume separately for each height class. The number of measurements forming the basis of each average is also noted against the point. For this distinctive height class marks can be used as

⊗, ⊕, △, ⊙, etc.

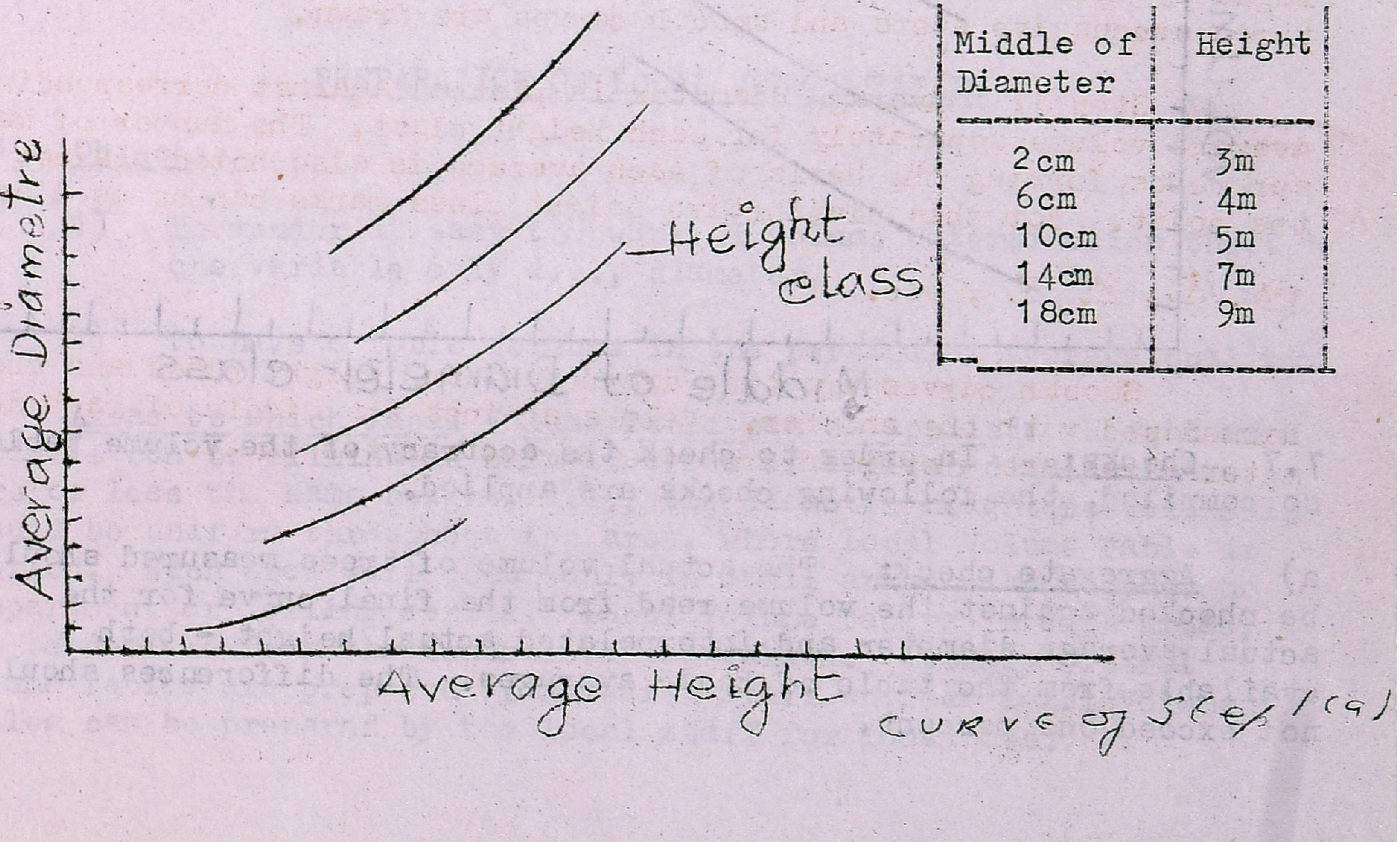
Smooth curves are then drawn for each height class and then harmonised with one another. Values against the middle of each diameter class are then read from the curves and tabulated.

Diameter class	Mid-diameter	Volume for each Height Class		
		0-4	4-8	8-12
0 - 4	2 cm	0.008	0.27	0.97
4 - 8	6 cm	0.022	0.48	1.28
8 - 12	10cm	0.048	0.79	1.54
12 - 16	14cm	0.098	1.10	1.92

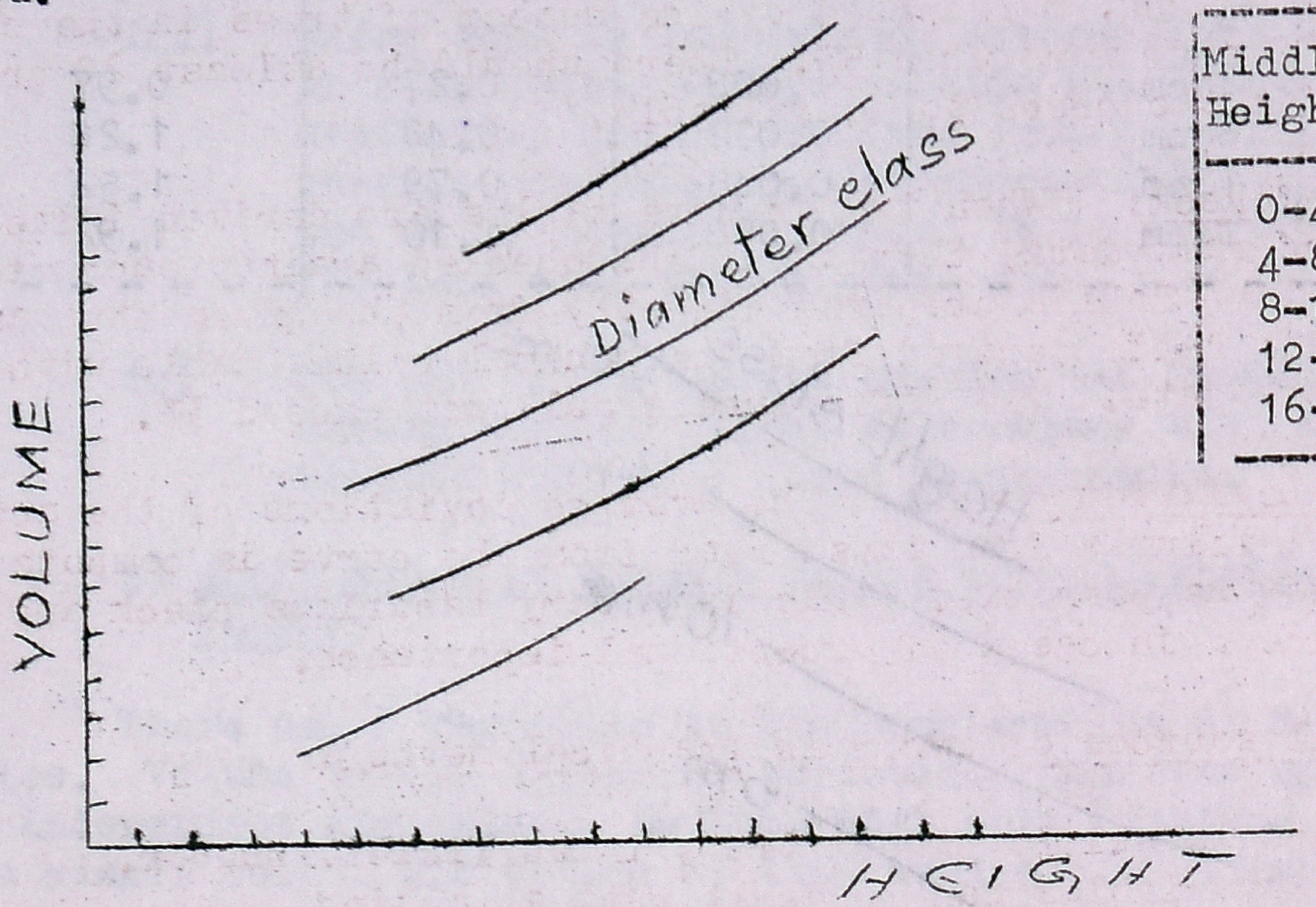


Step 1(a): Average heights given in the table of basic averages are plotted against corresponding average, diameter separately for each height class using distinctive marks for each. The number of measurements forming the basis of each average is noted against each point. Smooth curves are then drawn for each height class and harmonised with reference to each other. Average height against middle of diameter classes are then read from the curves and tabulated.

Middle of Diameter	Height
2cm	3m
6cm	4m
10cm	5m
14cm	7m
18cm	9m

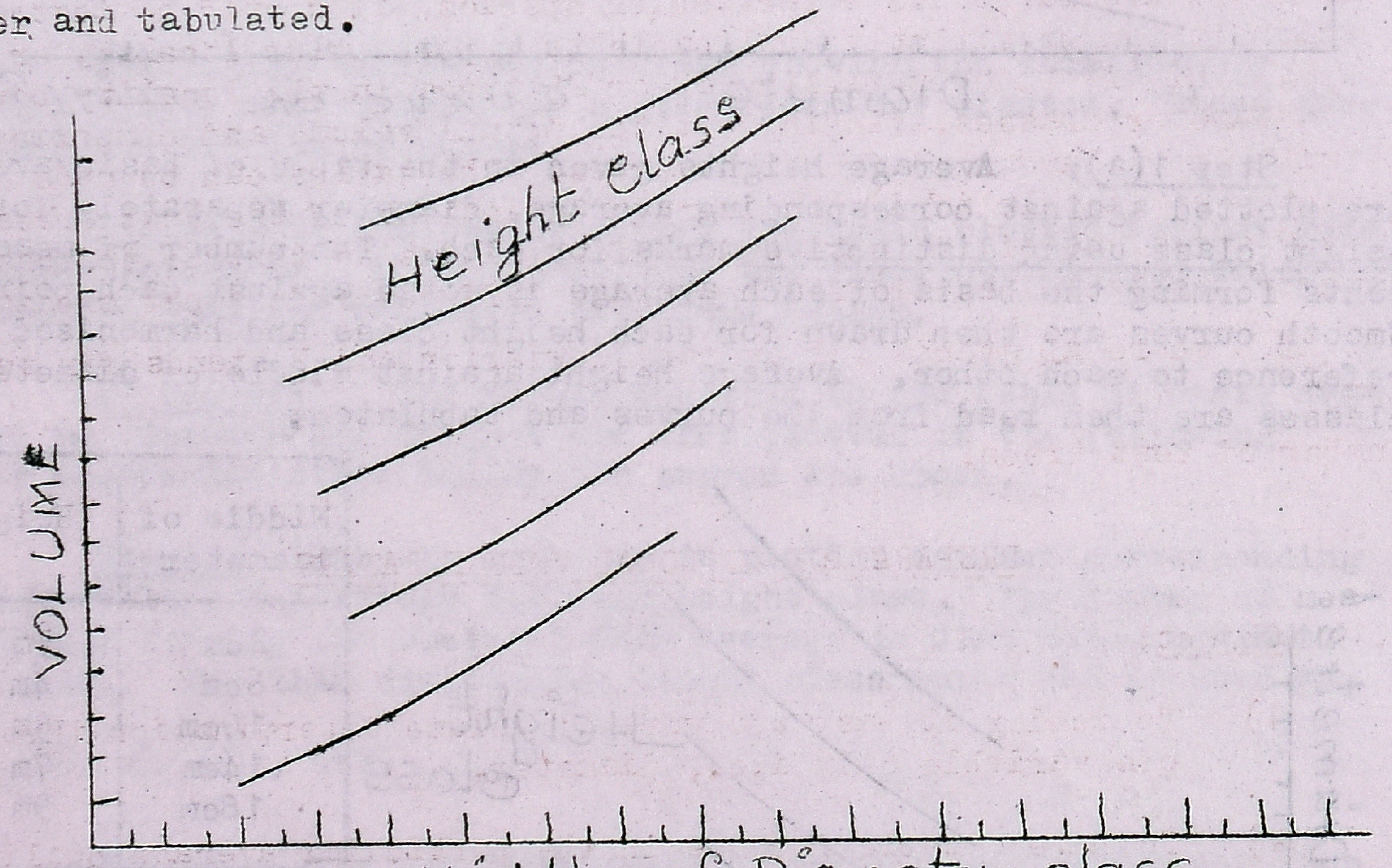


Step 2: The average volumes tabulated in step 1 are then plotted against corresponding average heights tabulated in step 1(a) separately for each diameter class, using distinctive marks for each class. Smooth curves are then drawn and harmonised. Volumes are then read from the curves against the middle of each height class and tabulated.



Middle of Height - class		Volume
0-4	2m	..
4-8	6m	..
8-12	10m	..
12-16	14m	..
16-20	18m	..

Step 3: The volumes read from curves in step 2 are again plotted against the middle of diameter classes separately for each height class. Smooth harmonised curves are drawn through these points. Final volumes are read from these curves against the middle of diameter and tabulated.



7.7 Checks: In order to check the accuracy of the volume tables, so compiled, the following checks are applied.

a) Aggregate check: The actual volume of trees measured should be checked against the volume read from the final curve for the actual average diameter and interpolated actual height - both available from the table of basic averages. The differences should not exceed one percent.

b) Height/Diameter class check: This check is merely an aggregate check applied to each diameter and height class. The difference between the total volume obtained from field data and corresponding volumes read from the curves against actual average diameter and interpolated actual average height, multiplied by the number of trees in the class should not differ by more than 5%. There should be atleast 20 trees in the class for the check to be reliable.

c) Relative check: When two or more tables are derived independently from the same data, they should be checked against each other (Eg.) Local Volume Tables prepared directly from the given data and the Local Volume Table derived from the general volume table with the help of the same data. The difference should not exceed 3%.

d) Average Deviation check: The average deviations of the actual individual tree volumes from those read from the curve is computed and should be as low as possible. This is a very laborious check and is not applied except in cases of exceptional importance.

7.8 Principal sources of error in graphical method:

1. Failure to select proper trees in sufficient number.
2. Only 2 variables can be dealt with at a time.
3. Drawing of curves always introduces a personal factor and consequent bias.

7.9 Applicability of General Volume Tables: When General Volume Tables are available for a particular species, it should be tested whether it can be directly applicable to a particular locality or coupe. This is made by felling 20 or 25 trees in the locality covering all diameter classes, finding out the actual volume and comparing it with the volume read from the curves. The tables can be made directly applicable if i) the average deviations of the test trees (say N trees) be of the same order of magnitude as that of the basic data of the table and ii) the aggregate difference does not exceed $\frac{2 \times AD}{\sqrt{N}}$ where AD stands for average deviation and N stands for the number of test trees.

PREPARATION OF LOCAL VOLUME TABLES

8.1 Object:

1) To render it easy the work of volume determination through one variable only i.e., diameter.

2) To have a table for use in the particular average quality.

8.2 Areas to which Local Volume Table can be applied: Height as a variable can be eliminated only if trees of a given diameter have more or less the same height, i.e., the diameter height relationship should be uniform throughout the area, where Local Volume Table is applied. Such area will occur only in small areas like a coupe or compartment or felling series. Local Volume Tables in such areas, can be derived from the General Volume Tables. Usually General Volume Tables are prepared by Research staff whereas Local Volume Tables can be prepared by the local staff for local use.

8.3 Local Volume Tables according to Site quality: We know that General Volume Tables cover several types of forests and site qualities and soil types. But the local forest officer is interested in knowing as to what particular figure he must take from the volume table to find the average volume of a tree of a given size of his forests or coupe. This can be done by measuring accurately both the diameter and height of a few trees - say 4 to 5 typical trees covering each of the diameter classes.

These trees should

i) have as nearly as can be judged, the average height of the trees of their diameter classes standing within their vicinity and

ii) they should be as widely and as regularly distributed as possible over the whole area in question. Otherwise each type of locality should be separately dealt with whenever difference is appreciable.

8.4 Procedure: There are 2 methods.

1) Graphical method and
2) Regression method.

The most commonly used method is graphical method. In both of the above methods, local Volume Tables may be prepared either directly from basic data of diameter and volume of trees or derived from the General Volume Tables of that species.

8.5 Graphical method based on basic data collected from field:

In this method, the diameter at breast height (o.b.) and volumes of sufficiently large number of trees are measured and recorded. Then the average volume for each diameter class is worked out. This is plotted against mean-diameter of the class and a smooth curve is drawn. Care should be taken to see that the diameter classes cover the entire diameter classes of the trees available in the locality. But this method involves calculation of volume of a large number of trees and hence this is a laborious and time consuming method. Hence it is rarely followed.

8.6 Derivation of Local Volume Tables from General Volume Tables by Graphical method:

We know that the General Volume Tables gives volume of a tree by diameter and height classes. These are generally based on data of trees collected from a wide range of distribution. If this General Volume Table is to be used, we want d.b.h. and height of individual trees. The Local Volume Table of a locality or coupe can be derived from the General Volume Table, with the help of measurement of d.b.h. and height of some standing trees in the locality. Following is the procedure.

1. Select 4 to 5 typical trees in each diameter class.

2. These trees should reprresent the average height of trees of their diameter class standing in the site.

3. These trees should be widely distributed over the whole area.

4. Measure the diameter at breast height and heights accurately of all these trees.

5. The heights for each diameter class should be averaged.

6. Draw a height/Diameter curve. If the points do not fit into a smooth curve, further measurements may be taken if possible.

7. Heights for any convenient diameters, such as the middle of the usual diameter classes should be read from this curve. For example, for 10cm. diameter classes, middle diameter may be 25cm, 35cm, 45cm, etc. For 4cm diameter classes, middle diameter may be 2cm, 6cm, 10cm, 14cm, etc. This can be tabulated as follows:

Diameter (cm)	Height (m)
25	18
35	22
45	25
55	28
65	33
75	37
85	40
95	44

8. The figures from the General Volume Table are plotted on a graph paper showing volumes against the middle of diameter classes for each height class separately. Volume may be taken in y axis and the diameter in x axis. Hence there will be the same number of curves as the number of height classes.

9. Each height class curve may be given a number equivalent to the middle of the height class to which it pertains, so as to distinguish them.

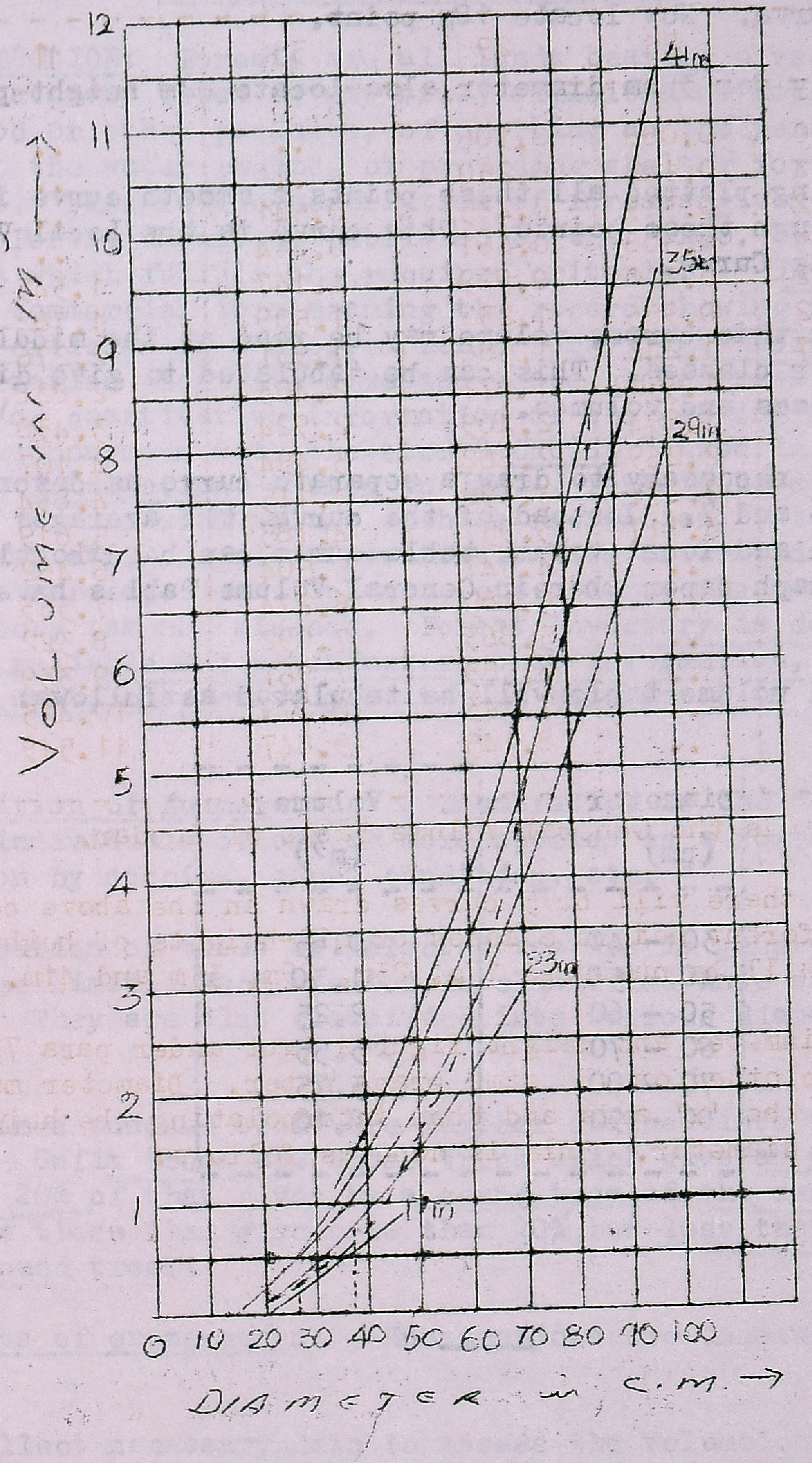
For example

D.B.H. (cm)	Volume (M^3)				
	Height(m)				
	17	23	29	35	41
15	0.030	0.068	0.106	..	..
20	0.114	0.182	0.250	..	..
25	0.222	0.329	0.435	0.541	..
30	0.355	0.508	0.661	0.814	..
35	0.512	0.720	0.929	1.137	1.345
40	0.692	0.965	1.237	1.509	1.782
45	0.897	1.242	1.586	1.931	2.276
50	..	1.552	1.977	2.403	2.828
55	..	1.894	2.409	2.924	3.438
60	..	2.269	2.882	3.494	4.107
65	..	2.677	3.396	4.115	4.834
70	..	3.117	3.951	4.785	5.619
75	..	..	4.547	5.504	6.462
80	..	..	5.185	6.274	7.363
85	..	..	5.863	7.092	8.322
90	..	..	6.583	7.961	9.339
95	..	..	7.343	8.879	10.415
100	..	..	8.145	9.847	11.549

Note: The above is the General Volume Table of deodar.

10. Thus, there will be 5 curves drawn in the above case for 5 different height classes or mid-heights of height classes. They will be numbered 17m, 23m, 29m, 35m and 41m.

11. The diameter and height figures (got under para 7) are then plotted on the same graph paper. Diameter may be taken along the 'x' axis and then interpolating the height against these diameter. This is done as follows:



Specimen graph showing derivation of Local Volume curve from General Volume Table Curve.

For example the diameter of first tree is 25cm and its height is 18M. Locate 25cm on the diameter axis of the curve. The same ordinate is followed up to locate 18m by simple rate of proportion. The curves already drawn are for 17m and 23m. Suppose the distance between the two curves at this point is 2cm, this gap of 2cm represents a height of 6m. Therefore, the point of 18m should be 2/6 cm above the 17m curve. Now locate 18m point.

Similarly for 35cm diameter also locate 22m height point and proceed.

12. Having plotted all these points a smooth curve is drawn through these points. This curve is the Local Volume Table Curve.

13. From this curve, volume may be read at the middle of diameter classes. This can be tabulated to give diameter classes and volumes.

<u>Note</u>: It is not necessary to draw a separate curve as described in para 5, 6 and 7. Instead of the curve, the averages may be tabulated and local volume table curve can be directly drawn in the graph paper wherein General Volume Tables have been marked.

The final volume table will be tabulated as follows:

Diameter (cm)	Volume (m^3)
30 - 40	0.65
40 - 50	1.30
50 - 60	2.25
60 - 70	3.55
70 - 80	5.75
80 - 90	8.10

<u>PROBLEMS</u>

1) Define Volume Table. What are the various kinds of Volume Table? What is the difference between General Volume Table and Local Volume Table?

2) Describe how you will prepare a Local Volume Table from (a) collecting data (b) from General Volume Table.

CHAPTER VII

ENUMERATION OF GROWING STOCK

1. INTRODUCTION: Forests are all lands bearing a vegetative association dominated by trees of any size, exploited or not, capable of producing wood or other products, of exerting an influence on the climate or on the water regime, or providing shelter for live stock and wild life. This is the description of forests given in the questionnaire of Forest Inventory published by the F.A.O. Hence forests mean, an area which fulfils the required criteria. " Inventory " is originally a commercial term meaning the record showing the quantity and value of articles in a store. Hence Forest Inventory has to provide information about the size and shape of the area and the qualitative and/or quantitative information of the growing stock. Forest inventory is synonymous with the term " CRUISE " used in North America or the Term " Enumeration " used in India. Forests have to be treated as important for non-wood values such as recreation, watershed management, wildlife, etc. Regular inventories have to be made about the wildlife, the rare species of plants, etc. Hence the concept of Forest inventory has now widened. Forest inventory is defined as the " tabulated, reliable and satisfactory tree information, related to the required unit, respectively units, of assessment in hierarchic order."

2. Definition of Enumeration: Enumeration is the "counting singly or together of individuals of one or more species in a forest crop and their classification by species, size, condition, etc. "

Enumeration of trees of selected species is generally done over a minimum size limit. Each species is classified into sound and unsound trees. They are also classified into various diameter or girth classes.

Sometimes unsound trees are further divided into fit trees and unfit trees. Unfit trees are those trees which give an yield which is less than 20% of that given by a sound tree of the same dimensions. Fit trees are those that give more than 20% but less than 80% of the yield of a sound tree.

3. Objects of enumeration: Enumerations are done with the following objects:

i) To collect necessary data to assess the volume of timber, growing in a forest, with a view to determine the yield.

ii) Less frequently for assessing the value of the growing stock for purposes of sale or exchange.

iii) To estimate the returns to be expected from clear-felling coupes.

iv) To determine the current periodic annual increments of crops.

v) To prepare a stock map showing regions of high and low volume per unit area.

vi) To help decision making in setting up of industries.

Hence enumeration will help in supplying information for forest management and planning and on pre-investment decision on forest industry establishment or expansion. These help in assessing the feasibility of a project from economic, social or any other considerations.

4. Kinds of Enumerations: It may be either i) Total (complete) or ii) Partial (or sample).

4.1 i) Total enumeration: means the enumeration of desired species above the specified diameter limit carried out over the entire area of the forest unit under consideration. This is very expensive and time consuming. This is resorted to only in the following circumstances.

a) When the standard of accuracy to be had is very high. Eg. sale or exchange of forest lands; P.B.I. areas of Uniform system.

b) For estimating yields from annual coupes.

c) For statistical studies undertaken to assess the precision of partial enumeration.

d) In case of small areas which are not having uniformity of stocking.

e) In the case of miscellaneous forests where the number of species is very large or economically important species are confined in small favourable localities.

Vastness of the forest areas, long time involved, lot of labour requirements, high expenditure required - etc. make total enumeration rarely adopted.

4.2 ii) Partial or sample enumeration: In this, enumeration is done only in a representative portion of the whole forest area. For example, a forest area may be of 1000 Ha. out of which a representative area of 50 Ha. or 100 Ha. will be selected for enumeration and estimation. The estimation of the whole area will be done by multiplying the estimated quantity with 20 or 10 respectively. Thus Partial enumeration is done in 5 to 20% of the area.

Sample is defined as a part of the population consisting of one or more sampling units, selected and examined as a representative of the whole. Therefore, sample enumeration is the enumeration of a representative part of the whole population. The ratio of sample to the whole population is called sampling fraction or intensity of sampling, which is expressed as a percentage i.e. 5%, 10%, 20%. Actual enumeration is done in a number of sampling units which are the subdivisions of the sample areas. For example, if sampling units of 1 ha. are made, there would be 100 sampling units in a sample of 100 ha. The record of each sampling unit is kept separately for working out the sampling errors and other statistical parameters.

5. Choice of the kind of enumeration: The choice between the two kinds of enumeration depends upon

i) Extent of area to be covered: When extensive areas are to be covered, partial or sample enumeration has to be done to save time, money and labour.

ii) Variation in composition and density: In areas where crop composition and density vary greatly, as in some miscellaneous type of forests, total enumeration has to be carried out.

iii) Intensity of management and consequent degree of accuracy required:

Where intensity of management is high and greater accuracy is required, as in P.B.I. areas of the shelter wood systems, total enumeration has to be done.

iv) Resources of labour: Resources of labour, time and money actually dictate the method of enumeration.

6. Relative advantages of sampling: Partial enumeration offers the following advantages over total enumeration:

i) Expenditure incurred is small.
ii) Details are got quickly.
iii) Though we have to demarcate several sampling units, this is better than total enumeration.
iv) A well planned, to an appropriate intensity, partial enumeration yields sufficiently accurate estimates of the growing stock.
v) Checking and re-checking is easy. Errors can be found out and calculated and rectified, if necessary.
vi) There is greater scope for use of sophisticated instruments and highly skilled techniques.

7. Kinds of Sampling:

PARTIAL ENUMERATION

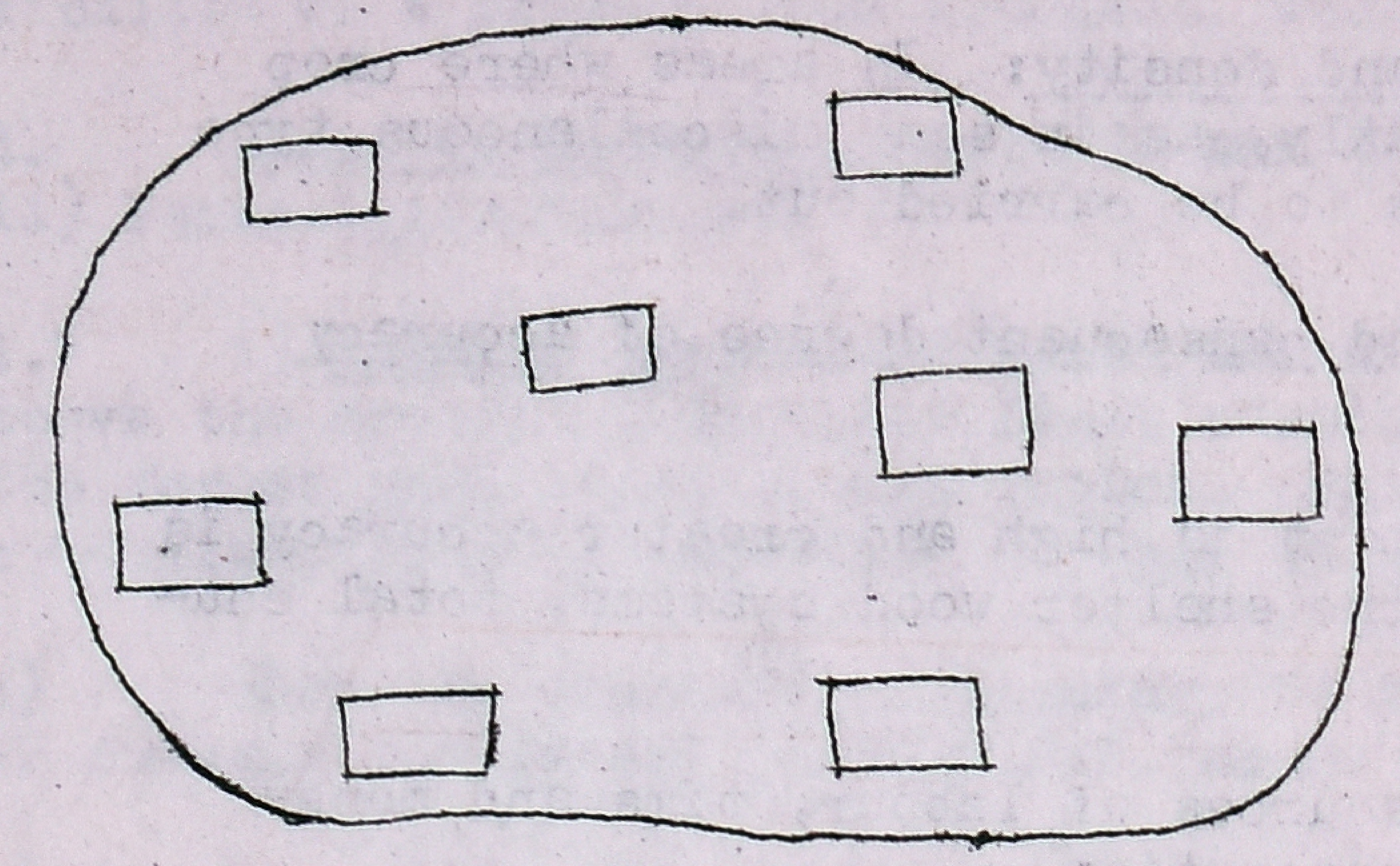
- SAMPLE PLOT METHOD
  - RANDOM SAMPLING
    1) Un-restricted Random sampling
    2) Stratified Random Sampling.
    3) Multistage sampling
    4) Multiphase sampling
    5) List sampling
  - NON-RANDOM
    1) Selective sampling
    2) Systematic sampling
    3) Sequential sampling
- LINEAR STRIP

Note: Let us study only those methods that are in our syllabus. Item 3,4 and 5 of Random sampling and Non-Random sampling are not in the syllabus for the Rangers Course.

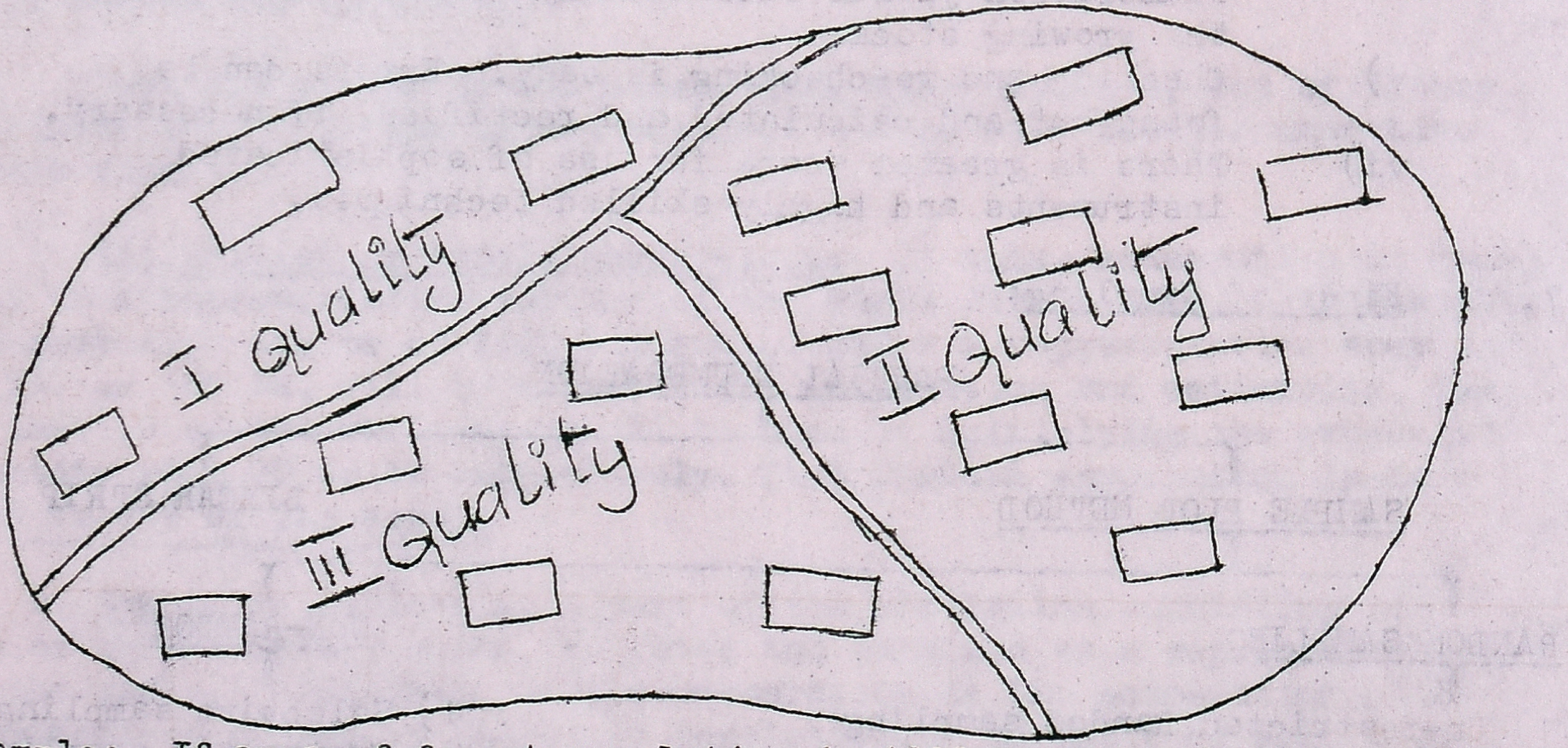
7.1 A. Random Sampling: In this method, sampling units are so selected that all possible units of the same size have equal chance of being chosen. The sampling units are selected by using a table of random numbers, by unbiased drawing of cards from a well shuffled pack or drawing lots. Following are the methods used.

7.2 i) Unrestricted or simple random sampling: This can be adopted where the growth is uniform in the area. In this method, every unit in the population is given equal chance of being selected. Population

is defined as the aggregate of units from which a sample is chosen. The required units are selected at random, employing a process of selection equivalent to drawing lots from the population of units. For example, if the sampling unit is 0.1 Ha. and the population area is 1000 Ha., the population is divided into 10,000 units. For a 5% unrestricted random sampling, 500 different four digit reference numbers are selected by using a table of random numbers. Hence every possible set of 500 units has equal chances of being chosen for the sample.



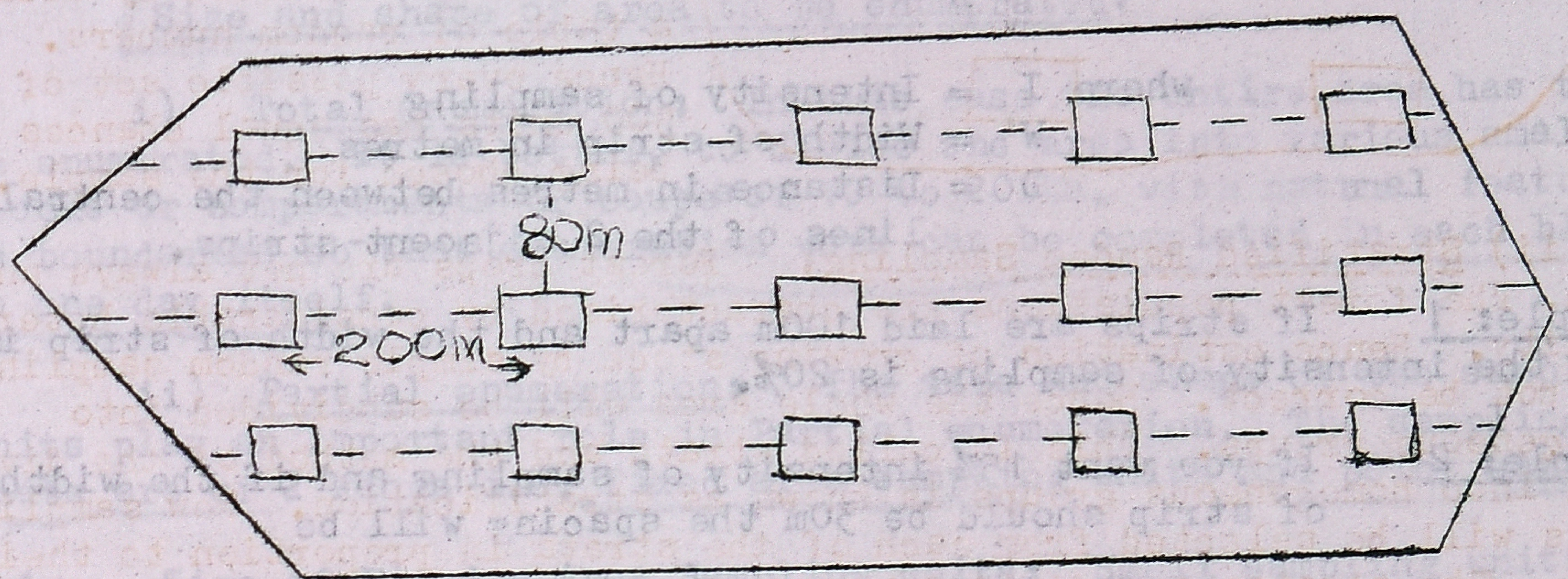
7.3 ii) Stratified Random Sampling: Forest crops are not always uniform. The forest populations are characterised by considerable heterogeneity. Hence estimation of growing stock by simple random sampling may not be correct. Hence the whole area will be subdivided into homogeneous groups. This is called strata and the method of the division into homogeneous groups is known as stratification. Now sampling units will be selected from each of the strata in proportion to their size. The stratas are divided by species, site qualities, crop density, etc.



Example: If area of forest population is 1000 Ha., and if the area is divided into 3 strata depending upon the site qualities, with area of 300 Ha. in I quality, 250 Ha. in II quality and 450 Ha. in III quality and sampling units are of 0.1 Ha. then for a 5%. Sampling 150, 125 and 225 sampling units will be selected with the help of table of random numbers or by drawing lots from strata of quality I, II and III respectively.

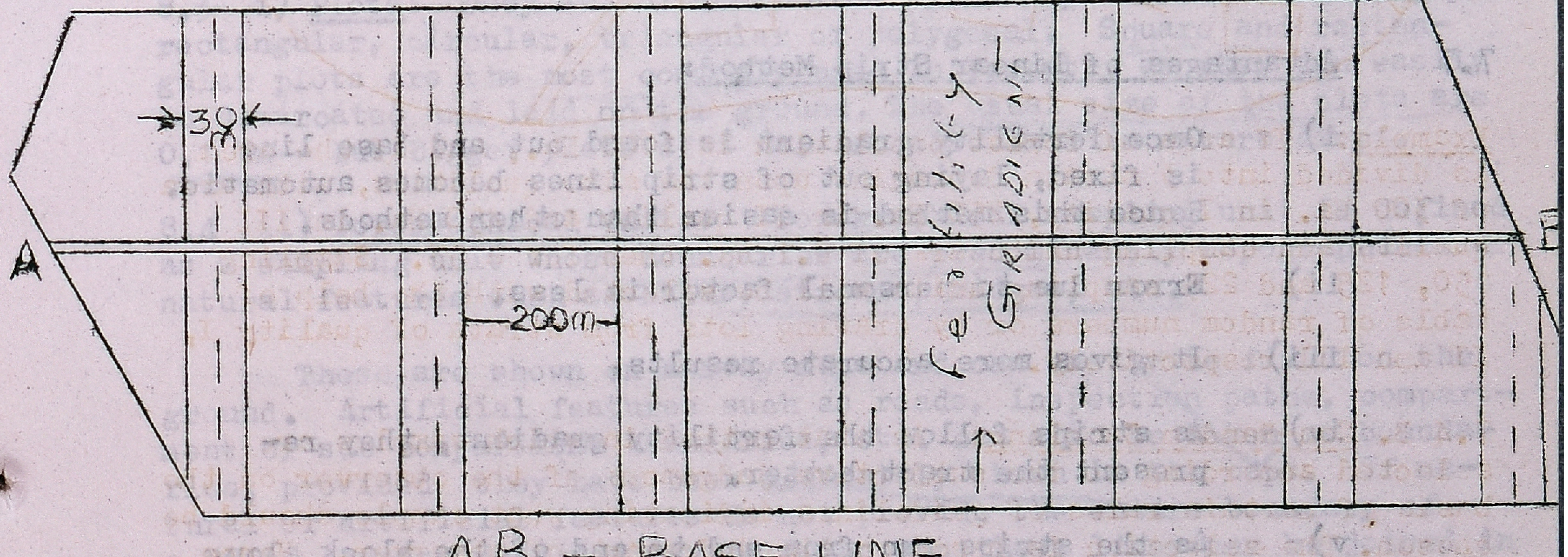
7.4 B. Non-Random Sampling: is that method in which samples are selected according to the subjective judgement of the observer on the basis of certain rules of guidelines indicating what sample should be chosen. The selection is based on the judgement of observer. Hence it is likely to be biased.

7.5 i) Systematic Sampling: This is one of the methods of Non-Random sampling. In this, sampling units are selected in a predetermined pattern. Mostly the pattern envisages regular spacing of units. Series of plots of uniform area are placed arbitrarily along compass lines at specified intervals of distances. The plots may be square, rectangular or even circular. This method becomes a modified version of linear survey. For example, sampling units may be located 80m. apart in rows which may be 200 m. apart. The first unit may be selected at random or according to a fixed arbitrary rule.



The advantage is that it saves considerable time in the collection of field data as location of sample plots is done easily. Hence this is frequently used in forestry. But this is not suitable for areas having variation in quality without a pronounced fertility gradient. First unit should always be selected at random and subsequent units may be fixed at equal intervals.

C. Linear Strip Method: Instead of laying out plots, continuous strips of uniform width spaced at regular intervals are laid out on compass lines. Enumerations are carried out in these strips. The strips are laid out parallel to fertility gradient so that they cut across the varying types of growth met with in the area.



The strips may be of 20 to 40m wide. A base line AB is fixed at one end of the forest. Lines are cut through a fixed bearing from a fixed point on the base line. This line is the central line of the strip on both sides of which enumeration is done. Then next line is marked and enumerated.

The width of the strip and the distance between the two strips determine the intensity of sampling. This can be calculated by the following formula.

$$I = \frac{W}{D} \times 100$$

where I = Intensity of sampling
W = Width of strip in metres
D = Distance in metres between the central lines of the 2 adjacent strips.

<u>Example: 1</u> If strips are laid 100m apart and the width of strip is 20m, the intensity of sampling is 20%.

<u>Example: 2</u> If you want 15% intensity of sampling and if the width of strip should be 30m the spacing will be

$$I = \frac{W}{D} \times 100$$

$$15 = \frac{30}{D} \times 100 \quad \text{i.e.} \quad \frac{3000}{D}$$

$$15D = 3000; \quad D = \underline{200 \text{ m}}.$$

7.6 <u>Fertility gradient</u> is defined as the variation in natural fertility in any direction across a forest area.

The volume production may rise in certain areas and fall in some other areas. This is due to site quality, changing from place to place. Sometimes this rise may be in a particular direction - say from bottom of a hill to the top of the hill slopes. Hence strips should always be formed parallel to fertility gradient so that it will represent the entire area.

7.7 <u>Advantages of Linear Strip Method:</u>

i) Once fertility gradient is found out and base line is fixed, laying out of strip lines becomes automatic. Hence this method is easier than other methods.

ii) Error due to personal factor is less.

iii) It gives more accurate results.

iv) As strips follow the fertility gradient, they represent the tract better.

v) As the strips run from end to end of the block along the fertility gradient, the data obtained can form a reliable basis for a stock map showing the density and composition of the crop.

vi) The position of strips can be determined even subsequently. Hence they can be treated as sample plots of semi-permanent character to assess the rate of growth and increment.

vii) The strip can be deemed to contain many one acre sample plots. This means there is a multiplication of samples without any extra cost.

8. Size and shape of area to be enumerated:

i) Total enumeration: In this case the entire area has to be enumerated. It is better, to divide the area into various small blocks or compartments or coupes of 10 to 20 Ha. with natural features as boundaries so that enumeration work can be completed in each block in one day itself.

ii) Partial enumeration: The size and shape of the sampling units play an important role in Partial enumeration. The sampling units are of 2 kinds i.e. fixed area sampling units and point sampling.

8.1 Size of Fixed - Area Sampling units: Small sampling units are more efficient, than larger ones because the larger the number of independent sampling units observed, the better the precisions. For a given intensity of sampling, the smaller the size of the sampling units, the larger will be their number and vice-versa. Though enumeration will be easier and quicker in smaller plots, their laying, clearing the areas, walking from plot to plot, etc. will be costlier and difficult. Hence the choice of size of sampling units should be a compromise between maximum efficiency, cost and convenience.

8.2 Shape of fixed area sampling units: The shapes should be of a regular geometric shape so that the area of the plot may be easily calculated. The sampling units may be plots, strips, topographical units and clusters. We have already discussed about strips. Let us see the other units.

8.3 i) Plots: They are of small area with shapes such as square, rectangular, circular, triangular or polygonal. Square and rectangular plots are the most commonly used in forestry as they can easily be demarcated and laid on the ground. The usual size of the plots are 0.1 Ha - but bigger plots of 1 Ha. are also laid in mature crops.

8.4 ii) Topographical units: Topographical sampling unit is defined as a sampling unit whose boundaries are predominantly topographical or natural features such as Nalas, streams, ridges, etc.

These are shown on survey maps and can easily be fixed on the ground. Artificial features such as roads, inspection paths, compartment or sub compartment boundaries, etc. can also be taken as boundaries, provided they have been accurately shown in the maps. If natural or artificial features do not provide the entire boundary of a unit, compass readings may be taken and these lines may be joined in the maps.

Topographical units are mostly used in hill forests as sampling units - where other survey methods are difficult. Once the sampling intensity has been decided, compact portions of the total area to be

enumerated (after deducting in accessible and unworkable areas) are divided into topographical units of convenient size of 12 to 24 Ha - first on the map and then on the ground. The units are then stratified into homogeneous blocks such that the enumerations of atleast two units per block gives the desired intensity of sampling. Suppose the compact area is very small, two more compact areas lying closely may be included to make it as one unit. It may be difficult to arrange units of comparable site quality since altitude, aspect, slope, etc. decide the vegetation and productivity. But the best efforts should be attempted. It is quite essential that the boundaries are clear in the map as well as in the ground.

The size may be bigger in this method. Hence the number of sampling units will be less. Hence the standard error may be more than in the method of plots or strips.

8.5 iii) Cluster: Cluster is defined as a sampling unit, which is, in fact, a group of small units. The cluster is the statistical unit whereas the smaller ones are only record units. Information is collected separately in each record unit and is then merged with information from the other record units to constitute the information related to the cluster.

9. Sampling intensity: Sampling intensity refers to the percentage of the area of the population to be included in the sample. This depends upon

i) the object of inventory

ii) the type of forest being inventoried

iii) kind of sampling to be used

iv) time and money and labour available

v) degree of accuracy aimed at and

vi) precision required.

Advanced sampling techniques can reduce the intensity of sampling. But they require trained staff for their execution, in the field and processing the data in office.

Griffith has recommended the following intensities for various types of forests.

i)	Tropical wet evergreen	..	10%
ii)	Tropical moist deciduous	..	2.5%
iii)	Sub-tropical pine forests	..	5%

The percentage recommended for different terrains are as follows:

Terrain	Method	Percentage of sampling
i) Plains	Strip sampling ..	5 to 10%
	Line Plot survey (0.05 Ha. circular equidistant plots on parallel lines) ..	2 to 5%
ii) Hills	Topographical units ..	20 to 25% when the area of the forest is more than 2000 Ha.

The intensity of sampling can considerably be decreased if the area is extensive and sampling units used are small.

Method of Enumeration and organisation of Field work:

10.1 General Rules:

i) In each case, a minimum size limit down to which enumerations will extend should be determined.

ii) Worthless trees should not be enumerated.

iii) Except when required, dead and dying trees should be separately recorded.

iv) Trees that fork below the breast height should be counted as two trees.

v) Important trees should be kept separately. But species of minor importance occuring here and there need not be distinguished.

vi) Unless specified, standard diameter classes of 10cm, 5cm and 2cm should be followed.

vii) Otherwise standard girth classes of 30cm or 10cm should be adopted.

viii) Diameter and girth classes to be distinguished depends upon the object of enumeration.

ix) Standard rules for measuring diameters should be followed.

x) When standard rules are not followed due to buttress, etc., the details as to how and at what height the measurements were recorded should be noted along with reasons.

xi) The bark of each tree should be marked after enumerating with a scribe. This will help in identifying that this has been enumerated.

xii) Coloured callipers can be used if it is measured by illiterate persons.

10.2 A. Total Enumeration:

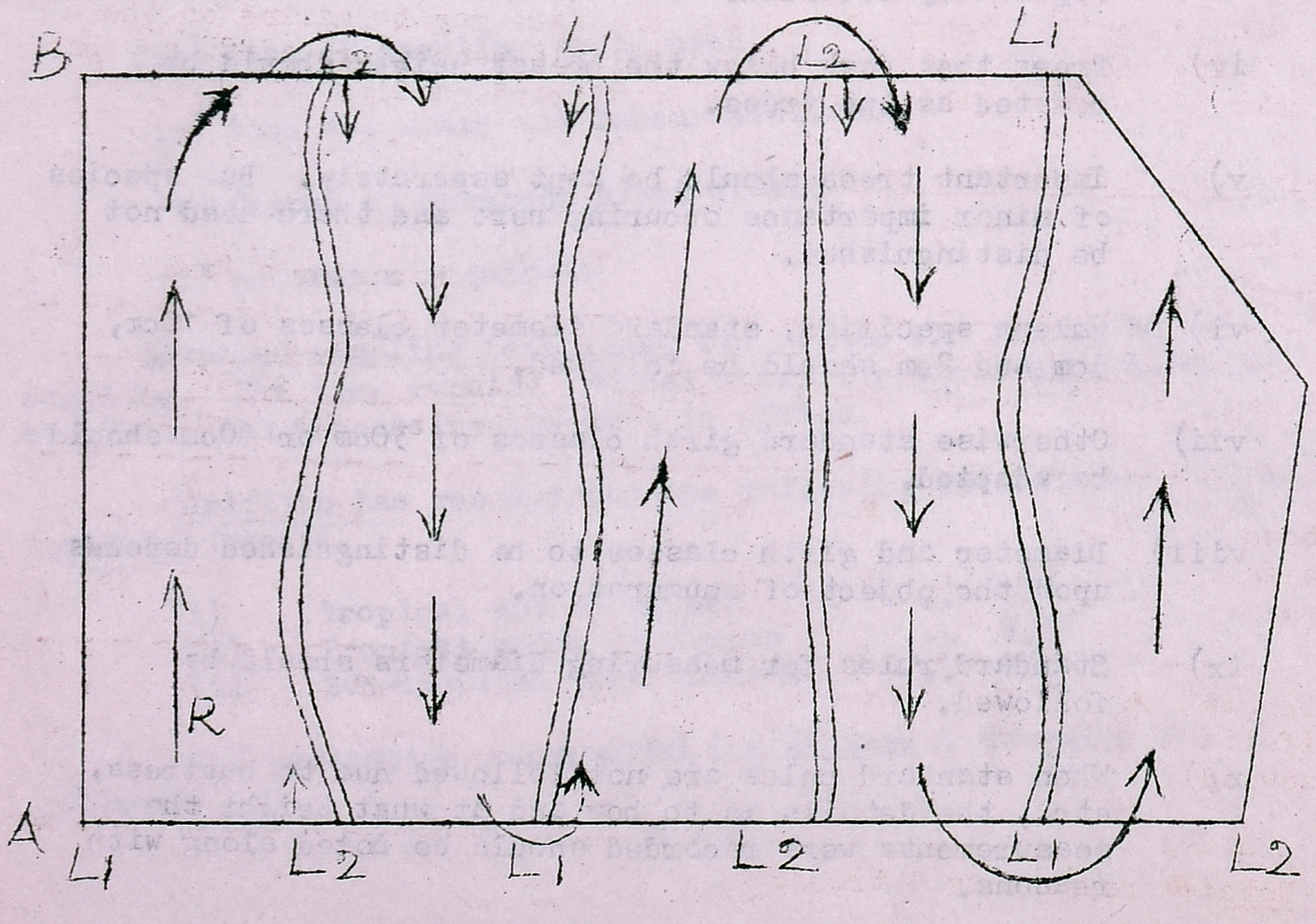
i) Field Equipments:

Callipers or tapes	..	6
Scribes or chalk	..	6
Bill hooks	..	2
Steel tape	..	1

Coal tar - sufficient quantity to mark the boundary of coupe.
Enumeration Book and pencil.

ii) Field organisation (Personnel): The party shall consist of one enumerator and seven mazdoors. Out of these seven mazdoors, two mazdoors act as linesman and go on making blazes to indicate the area enumerated. They shall also keep with them tape or callipers and enumerate the trees near their line and mark them with chalk or scribe. The other four are regular tape or callipermen, who will measure the trees and mark them with scribe or chalk. The seventhman is the watchman of the camp. He can be utilised for carrying drinking water, etc. During summer, an extra man can be engaged for bringing drinking water to the working group.

iii) Method of Enumeration: The work is started from one end of the compartment along one of its sides. A strip of about 40m is taken up roughly. The width of strip may be still less in denser forests. The enumerator or recorder should be able to follow the positions of the linesmen and calliper men. The 2 linesmen will be on both sides of the approximate strip. The whole party will proceed in a team. They will keep their position within the strips by looking at the man towards the permanent line.



All the trees of the species to be enumerated above the minimum diameter fixed for the purpose are enumerated. The calliper or tapeman, on reaching a tree takes the measurement of d.b.h., calls out the measurement along with the name of the species - to be recorded by the enumerator. The recorder should follow the callipermen carefully and ensure that they measure correctly by observing all the standard rules. As the calliperman shouts the measurements and name of the species, the recorder should record it and shout back the measurements and species to the calliperman. The calliperman shall not move from that tree until the enumerator shouts back. Then he marks the tree with chalk or scribe. In this way, the enumeration goes on till the party reaches the other end of the compartment. Then the process is reversed.

The linesman who was walking along the fixed boundary of the compartment goes to a fresh point about 40m from the point of other lines man who remains at his position and goes back along the line that he had marked while in the previous strip. After all the workers take their position, the enumeration in the new strip is taken up. The enumerator will always remain at the centre of the strip. He can also go this side or that side to check the work of tapemen.

These strips may not be straight ones. They may be wavy or irregular. Thus the work will be completed in the compartment.

iv) <u>Recording</u>: Record of total enumeration is kept by compartment or sub-compartment, giving one page of the enumeration book for one day's work. The area should be divided into 12 to 20 Ha. units with the help of natural features, so that the unit may be completed in one day. If this is not possible, the last line of the day's work should be thoroughly blazed and the date may be marked on the trees lying on the boundaries with indelible pencil or paint, so that the next day's enumeration work can be started easily.

<u>Specimen of Enumeration Book</u>

Division Date:

Compartment No. Recorder's Name:

Species	Sound 20-30 cm	Sound 30-40	Sound 40-50	Sound 50-60	Unsound 30-40 Fit	Unsound 30-40 Unfit	Unsound 40-50 Fit	Unsound 40-50 Unfit
Tectona grandis (Teak)	卌 ///	///	卌 ///	卌 //	//	/	//	//
Dalbergia latifolia (Rosewood)	卌 卌 ///	卌 ///	卌 //	///	//	/	///	//

<u>Note</u>: 卌 represents 5 trees.

v) Additional measurements: Additional measurements such as the heights of representative trees of each diameter class may be recorded in the course of enumeration. This will help in the preparation of volume Tables or for fixing the quality class. Notes regarding condition of regeneration, presence of pole crop, presence or absence of bamboo growth, etc. may also be made.

vi) Abstract: When the enumeration of the whole compartment is over, enumeration figures of all the days spent on enumerating it, are added up specieswise, totalling green and dry trees separately. The totalled figures are the figures of the total enumeration for the compartment.

10.3 B. Partial enumeration:

1. Linear strip method:

i) Field Equipment:

Prismatic compass with stand	.. 1
Bill hooks ..	.. 2
Callipers or Diameter tapes	.. 4 to 6
Scribes or chalk ..	.. 4 to 6
20 metre chain and arrows	.. 1
Ranging rods	.. 3
Bunteys ..	.. 3
20 m. long ropes ..	.. 6
Axe ..	.. 1
Steel tape ..	.. 1

Enumeration book and pencil and a large scale tracing of the map of the area with base lines, boundary lines and strips marked in it.

ii) Field organisation (Personnel):

Each gang will consist of 13 or 14 mazdoors besides the enumerator. Their duties are as follows:

a) 2 men for clearing the central line with bill hooks and carrying ranging rods.

b) 2 men for measuring the central line with 20m chains.

c) 4 men carrying ropes to mark boundary of the strip - two on either side of the chainmen.

d) 4 men to measure the trees.

e) 1 man to carry prismatic compass and stand.

f) 1 watchman of the camp as well as for carrying drinking water, etc.

11. Organisation of Field work (Linear Strip survey):

Partial enumeration requires some skill. Hence enumeration parties should be given detailed instructions regarding the conduct of work so that they understand the methods clearly. It is desirable that a field demonstration is given to each gang so that each member of the gang understands his job.

11.1 A. Instructions to enumerators: Following points should be covered while giving instructions to the Enumerating gangs.

a) Use of maps, method of locating on ground the central line marked on the maps or tracings and marking the start and end of the lines with prominent blazes on trees.

b) Use of compass, method of clearing the central line including fixing pegs at regular intervals; keeping correct direction, measuring the central line with chain, etc.

c) Method of maintaining the width of the strip with ropes.

d) List of species to be recorded; the lowest diameter above which enumeration is to be done; diameter classes with their lower and upper limit, classification into sound or fit or unfit, green and dry.

e) Correct method of using callipers, diameter tapes, method of calling out, system of marking enumerated tree with scribe or chalk.

f) Notation for recording measurements in the field book - instructions about closing the enumeration at the end of the recording unit as well as at the end of the day.

g) Preparing necessary sketches and notes along side of enumeration work, for mapping the stock as an additional item of work.

h) Rules regarding breast height measurements.

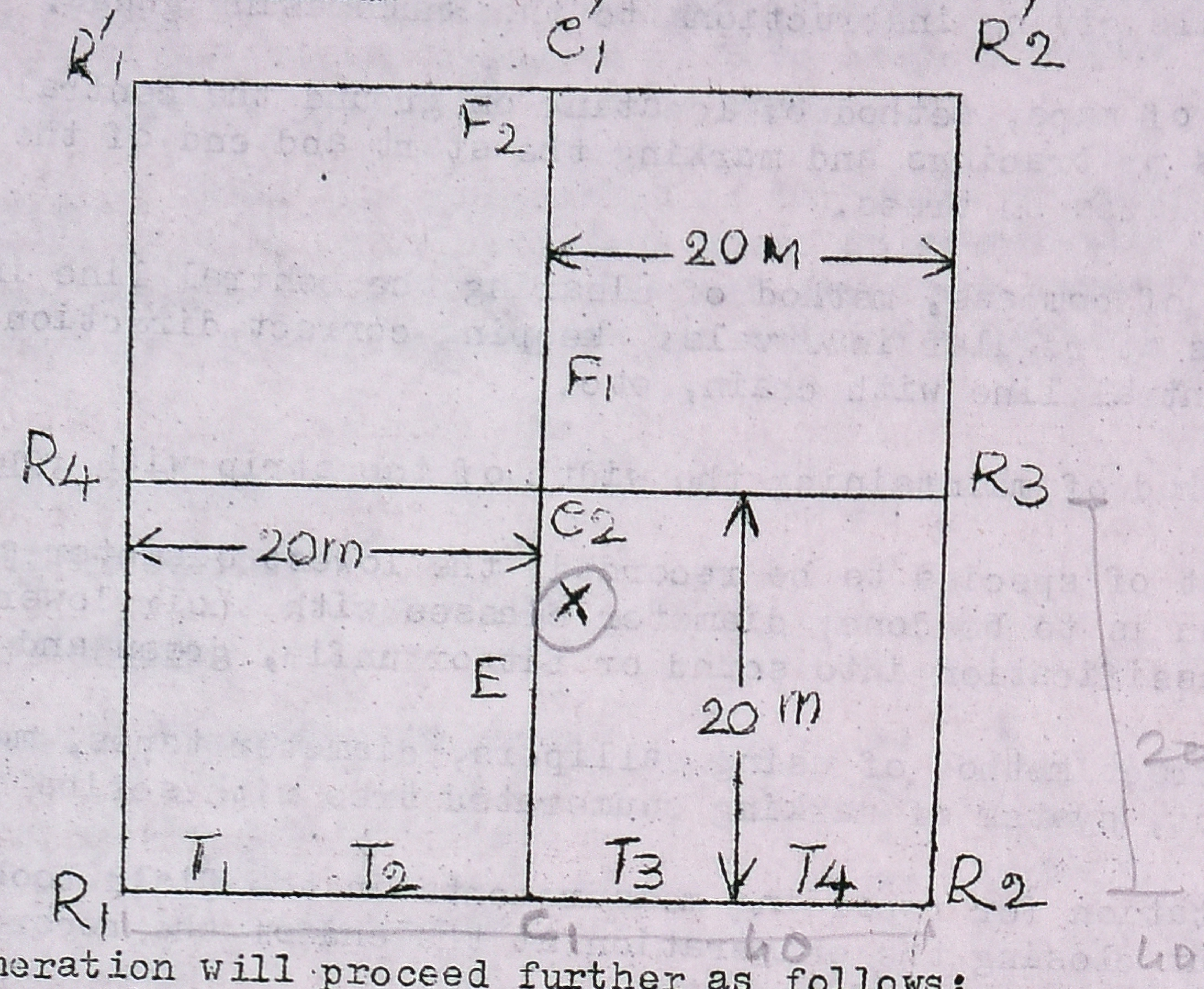
i) The code for deciphering the appropriate diameter class, when coloured callipers are used.

j) Office work at the end of the day's work and after completion of work in a compartment - such as inking the figures of information, totalling, abstracting and submission of enumeration books after completion of work.

k) Directions for sketches or notes for stock map to be prepared while enumerating.

11.2 B. Starting: Locate the point from which the enumeration is to be started. This point would already be there in the map given. The distance from the known point will have to be measured in the particular direction and the starting point can be fixed easily. A peg is fixed at this point. The number of strip or grid is written in the peg with pencil. This number is also written on the blaze of a tree nearby. Then the enumerator will fix the prismatic compass on this peg and direct the ranging rod men to clear the shrubs, if necessary, on a particular bearing, (as per the map) so that the cleared central line represents the line on the map.

11.3 C. Proceding further:



Enumeration will proceed further as follows:

C1 and C2 are the 2 chainmen.
E is the enumerator at the centre of the starting line near C1.
R1, R2, R3, R4 are the 4 ropemen each 20m. away from the chainman C1 and C2.
T1, T2, T3, T4 are the Tapemen who measure diameters of trees.
F1 and F2 are the Ranging rod men in the direction of the line.
F1 is about 10m. from C2 and also from F2. There is another ranging rod at (X). 6 pieces of rope, each 20m long connect C1R1, R1R4, R4C2, C2R3, R3R2 and R2C1.

After the party has been organised as shown in the diagram, the tapemen enumerate the trees within the rectangle. As and when a tree is seen they will measure and call out the measurement of the tree along with species. The recorder will record it in the enumeration book and repeat the species and measurement to indicate that he has recorded. The tapemen will mark the tree that has been enumerated with a scribe or chalk. The tapeman shall not move from the tree until the measurements have been repeated by the recorder. Thus all the trees in that rectangle of 40mx20m will be enumerated.

Then C1 moves to C2 exchanging arrows with C2 and takes the end of the chain from C2 and drags it to the new position C'1 near F2. At the same time, R1 moves to R4, takes the end of the rope from R4 and moves it along to his new position R'1. Similarly R2 goes to R'2.

R1 and R2 also carry the ropes between them and C1 and on reaching their approximate positions, stretch the ropes between R'1 and C'1 and C'1 and R'2. Thus a rectangle is again formed. The trees are counted as described above. The ranging rod at X is lifted and the line is further ranged in lines, with the help of the other two fixed ranging rods. Then keep on cutting the central line also after fixing it.

The prismatic compass is set at every 4 or 5 chains and checked if the central line is cleared correctly. As the ropes are used, the boundary is well defined, and hence there is no possibility for mistake. Ropes are very important in areas with dense pole crop, as there will

not be any doubt whether the trees fall within the boundary or not. In areas where pole crops are not much, ropes need not be used. Only in case of marginal trees, ropes may be necessary to see if they come inside the strip or not.

After enumeration has been done in 5 chain (100m), a line is drawn in the enumeration book and record may be closed. A peg is driven on the ground and the number of the area finished and started is given on their respective sides.

When enumeration reaches the other end of the compartment, a stout peg is driven in the ground and the number of the line or grid is written on it. This number is also written on a blaze on a tree nearby. Then the measurement from this peg to next strip is measured from the map and this is laid on the ground also (with the help of map) and the next peg is fixed. The enumeration work will start from this peg in a reverse direction.

Record of this enumeration should be kept separately for each 100m length as well as for each strip (sampling unit) and also separately for each compartment.

The enumeration work may be made much valuable to collect other valuable information like regeneration, growing stock of valuable species in the classes below the diameter limits of enumeration, presence of other species which are not important, type of undergrowth, shrub, climber, etc. - for every 100 m unit - provided trained enumerators are employed. These informations will help in a long way for the working plan officers.

12. 2. Line plot surveys: For line plot surveys, each gang will have 10 men. The ropes and ropemen are not necessary. The maps supplied will have the boundaries of plots. The method of enumeration will be the same. Records will be kept for each plot instead of strip.

13. 3. Partial enumeration in hills by topographical units: The party will have 7 men i.e. 4 tapemen and 2 linemen and one watchman besides the enumerator. The equipment is the same as that for total enumerations. The field party goes to the field with the map of the area showing topographical units and the units to be enumerated. With the help of the map and natural features, the topographical units are clearly marked in the ground, by coaltar ring marks on trees along boundary. Then the enumeration is done in the same way as under Total Enumeration. The record of each unit is kept separately.

PROBLEMS

1) Define enumeration. When will you resort to Total or Partial Enumeration? What are the objects of enumeration?

2) Explain in detail as to how you would organise and carry out (a) Total enumeration (b) Linear Strip enumeration.

3) Write short notes on (a) Random Sampling (b) Non Random Sampling (c) Topographic units.

CHAPTER VIII

MEASUREMENT OF VOLUME OF WHOLE WOODS OR FOREST CROPS

1. Introduction: We have studied the methods of measurement of diameter, height, form and volume of individual trees. But Forest crops consist of trees. The methods of measurement of individual trees do not apply to the measurement of forest crops due to the following reasons.

a) Gradual diminution of number: Most of the forest crops start with a very large number of plants. As they grow, there is a competition between the individuals. Several plants suffer from death and decay at various stages. With such death of younger trees, the average diameter and heights of several trees increase. Similarly the old mature trees die. This will cause in reduction of average diameter and height of the crops. Hence the average diameter, height, etc. change due to gradual diminution of the number of trees.

b) Stand structure: In a forest, the crops are mixed or pure, regular or irregular and distribution of age and/or the size classes differ from place to place. The growth of trees depend upon the site quality,soil factor, etc. It also depends upon the size and form of the neighbouring trees. Hence methods of measurement of different dimensions of the crop may have to be changed with the type of the forest that stands in the forest area.

c) Objects of measurement: In the case of individual trees, the object may be to find out the rate of growth of the individual tree. But in the case of a crop, the object may be to find out the behaviour of the crop as a whole. It may also be to find out the number of trees, crop diameter, crop height, distribution of trees by various sizes and volumes, etc.

Hence it is essential to study the methods of calculation of various dimensions of a crop.

2. Object: To have a knowledge of the volume of the whole woods for purposes of management of that forest, sale and research.

3. Determination of Diameter: Diameter has to be found out for determination of the volume. But volume is dependent on basal area. Hence, the diameter is based on the mean basal area and not on the mean diameters alone. There are two terms in diameter.

i) Crop Diameter is the diameter corresponding to the mean basal area of a uniform, generally pure crop.

ii) Mean Diameter is a diameter corresponding to the mean basal area of a group of trees or a stand. Sometimes used for arithmatic mean of summated diameters.

There is some difference between the two terms. Crop diameter is used for even-aged pure crops but mean diameter is used to any group of trees or any forest. Thus mean diameter is a general term but crop diameter is a specialised term applied to only evenaged pure crops. Both are obtained by finding out the mean basal area.

For this, the diameters of the trees are measured and are classified by diameter classes. The number of trees in each diameter class is multiplied by the basal area and then basal areas of all diameter classes are totalled and divided by the number of trees to get the mean basal area.

Thus mean basal area is obtained by the following formula.

$$\text{Mean basal area} = \frac{n1S1 + n2S2 + n3S3 + \ldots\ldots}{n1 + n2 + n3 + \ldots\ldots\ldots\ldots}$$

where n1, n2, n3 are the number of trees in each diameter class.

S1, S2, S3 are the basal area of mean trees of different diameter classes.

Crop diameter is the diameter of the trees corresponding to the mean basal area, found out above.

iii) Another method: Mean diameter may be calculated as an arithmatic average of the diameter of trees i.e.

$$\text{Mean Diameter} = \frac{n1d1 + n2d2 + n3d3 + \ldots\ldots\ldots\ldots}{n1 + n2 + n3 + \ldots\ldots\ldots}$$

where n1, n2 and n3 are the number of trees in each diameter class.

d1, d2, d3 are the average diameters of these diameter classes.

But this will not be the crop diameter. Because volume is proportional to basal area i.e. square of the diameter. Further crop diameter is so defined that it is based only on mean basal area. The mean diameter obtained through the mean basal area is always smaller than that obtained by the direct average of diameter.

iv) Top Diameter: It is the diameter corresponding to the mean basal area of the biggest trees in a uniform generally pure crop, taking into consideration 250 biggest diameters per ha. This is used for determining the Top height of a crop which is used to assess the site quality.

4. Determination of height of crops: Like diameter, the height of the crop is described by the following 2 terms.

4.1 Crop height is the average height of a regular crop, as determined by Lorey's formula.

$$\text{Crop height} = \frac{s1h1 + s2h2 + s3h3 + \ldots\ldots\ldots}{s1 + s2 + s3 + \ldots\ldots\ldots\ldots\ldots}$$

where s1, s2, s3 are the total basal areas of each of the diameter classes.

h1, h2, h3 are the average height of each diameter class, as read from diameter/height curves as calculated from the basal area.

This height is known as the crop height. This method is more reliable as the crop height is shown in the proper perspective as a function of the basal area.

How to find out crop height? Measure diameter of large number of trees and classify them into diameter classes. Assess the mean sectional area for each diameter class. This is called S1, S2, S3, etc.

For each diameter class, calculate the mean diameter from the respective mean basal area. Select 4 or 5 typical trees for each diameter class group, which will more or less represent the mean diameter and measure their heights. These heights may be averaged. A smooth curve may be drawn between the height and diameters. From the curve, the heights for each diameter class may be read. These heights are h1, h2, h3, etc. Now apply Lorey's formula.

Routine purpose: For routine purposes, a curve need not be drawn. The average heights for each group may be taken as h1, h2, h3, etc.

4.2 Mean height: It is the height corresponding to the mean diameter of a group of trees or the crop diameter of a stand. For this purpose, a height diameter curve has to be drawn from the data collected on a sufficiently large number of trees classified into diameter classes. The height and diameters of individual trees are plotted and a smooth curve is drawn. Then the mean crop diameter is calculated by the formula given earlier. Against this mean diameter, height is read from the curve and this height is the mean height.

Mean height may also be obtained from the mean heights of various diameter classes as follows:

$$H = \frac{n1h1 + n2h2 + n3h3 + \ldots\ldots\ldots\ldots}{n1 + n2 + n3 + \ldots\ldots\ldots}$$

where H = mean height of the woods.

n1, n2, n3 .. Number of trees in successive diameter classes.

h1 h2 h3 .. mean heights of respective diameter classes.

4.3 Top height: Mean or Crop height is used for determining the volume of a crop. But for assessing site quality only Top height is used. Top height is defined as the height corresponding to the mean diameter (calculated from basal area) of 250 biggest diameters per hectare as read from height diameter curve. Thus the crop or mean height refers to all the trees of the crop. But Top height selects to only 250 biggest diameters of the crop.

Top height represents the average height of dominant trees of a crop. This is found out as follows. Select the tallest trees in a given crop at intervals of 10m. Measure their heights and average them. This is the usual normal practice for finding the Top height, which is a more reliable index for assessing the productivity of a site than other growth factors like diameter, volume, etc.

5. Determination of Volume of Crops: Volume of crops cannot be determined by direct measurements of trees available in the whole forest area. Hence volume of crops over small areas is either estimated with the help of volume tables or with the help of studies made in small plots representing the crop. When volume table is used, the crop in the small area is enumerated and classified by diameter classes. If the local volume table is available, then the number of trees in each diameter class is multiplied by the volume corresponding to the diameter class given in the table and the sum of the

volumes of all diameter classes is the volume of the crop in that area. If local volume table is not available, the diameters and heights of a few trees are measured to prepare local volume tables from General Volume Tables.

The volume of a wood may be determined by any of the following methods:

1. Estimating methods.
2. Measurements extending over the whole wood.

5.1 Estimating methods:

i) Estimating with reference to area as a whole or if the area is known on the basis of estimate of unit areas:

This is the oldest and roughest method. The estimator should consider the difference in the density of stocking, the average volume per tree, difference in the quality of the locality, etc. before forming his final estimate. Thisrequires great experience on the part of the estimator. Still this will result in considerable error.

ii) Estimating by trees: The volume of each tree is estimated separately and these individual volumes of all trees are added up to get the volume for the wood as a whole. Though this may be more accurate than the previous method, this is time consuming, as every tree has to be estimated.

iii) Estimates based on results of past fellings: If statistics of past fellings of more or less similar areas are available, the volume of the standing crop may be estimated after making some allowance for difference in age, density, height, etc. in individual cases.

iv) Estimating by means of Yield Tables: If we know the area, quality class and density of the crop, we can estimate the volume per acre from the yield tables if Yield Tables are available for the particular species and if it is an even-aged crop.

5.2 By measurements extending over the whole wood: This can be done in two ways.

a) By measuring all the trees in the wood: Each tree is measured separately and its volume is calculated either by the form factors method or volume table method. In the case of former method, diameters and heights have to be measured. In the later case, enumeration of the forest is to be done. Enumerated trees are classified into diameter classes and volume found out from the local volume table.

b) Determination of volume by measuring sample trees:

6.1 General: The trees found in the wood, whose volume is to be determined, are enumerated and divided into groups of diameter classes. The volume of these sample trees in each group is found out. Then rule of proportion is applied and the volume of trees falling in each group are calculated. By adding all these volumes we get the volume of the entire wood. But this method is applicable only in the case of regular crops in which the height and form factor will be more or less the same for all trees. Otherwise the height and form factor

will also have to be found out which will be laborious.

6.2 Systems: There are three systems of utilising the sample tree for the determination of volume of the crop.

A. From volume of concrete sample trees by applying the rule of proportion.

B. From volume of concrete sample trees by graphic methods.

C. From the volume of Abstract Sample Trees obtained from graphs and tables.

All the above systems involve sample trees. The following observations hold good in the case of all these methods.

6.3 Selection of Sample Trees: The sample trees selected should represent the mean tree of the crop or of the size classes, or groups of size classes, into which the crop is divided.

Theoretically, mean tree is the tree whose volume, when multiplied by the number of trees will give the volume of the crop or the particular diameter class it represents. But we are going to determine the volume. Volume is always based on the basal area. Hence the sample tree should have the diameter as near as possible to the diameter corresponding to the mean basal area. The sample tree should also have the same height, stem form and shape of crown as the average of the class to which they belong.

Selection of such tree is practically difficult. Hence the result depends upon the personal factor. Satisfactory method of selecing a tree is to measure a number of heights and calculate the arithmatic mean and find out the mean height. Otherwise a diameter/height curve may be drawn and height corresponding to the diameter may be found out.

6.4 Number of Sample Trees: There is no hard and fast rule. It varies with the circumstances. If there is much variations in sizes, more number of trees will have to be selected. For Research purposes, large number of trees will have to be selected.

6.5 Measurement of Sample Trees: The sample trees should be felled and measurements taken. If it is not possible, a ladder should be used for measurements. Their measurements should be determined from Taper Tables.

7.0 Methods of Volume Determination by Selection of Concrete Sample Trees:

Different methods have been developed in different countries by various workers. Some of them are of only academic interest. Let us study briefly some of the methods.

7.1 Method I: One Inch Diameter Class Method or Hossfeld's Method:

Hossfeld suggested that the trees found in the stand are enumerated and classified into as many small groups - i.e. one inch diameter classes (2.5cm). In such small group, the assumption that mean basal area tree is the mean volume tree - may hold good. After

classification, the mean diameter and the diameter corresponding to the mean basal area of each of the diameter classes is found out. One or more sample trees having this mean diameter are selected for each diameter class and the volume is found out for each diameter class by applying the following formula

$$V = \frac{v \times S}{s}$$

where V = Total Volume of diameter class
S = Total basal area of the class
v = Total volume of sample trees
s = Basal area of sample trees.

The sum of the volume of the various diameter classes will give the volume of the wood as a whole.

Illustration

ONE INCH DIAMETER CLASS METHOD

Diameter in inches	No. of trees	Basal area Sft S	Sample Trees: Diameter in inches	Sample Trees: Basal area Sft. s	Sample Trees: Volume in Cft. v	Total volume $v = \frac{v \times S}{s}$ cft
10	30	16.36	10.7	0.625	17.14	449
11	40	26.40	11.0	0.660	16.19	648
12	50	39.27	12.1	0.799	22.40	1101
13	45	41.48	13.1	0.936	25.93	1076
14	30	32.07	15.0	1.227	27.79	726
15	20	24.54	15.0	1.227	28.40	568
16	10	13.96	16.4	1.467	38.53	367
Total	225	194.08				4935 Cft.

Merits of the method: As small diameter classes are adopted, there will be less variation. Further more number of trees are used for measurement. Both these factors may give a high degree of accuracy.

Demerits: Too many sample trees have to be measured, which is not possible. Choice of sample trees from each diameter class is also difficult. Since the number of trees in each diameter class varies, different sample trees represent varying number of trees.

7.2 Method II: Arithmatic Mean Tree method: Determine the volume of the mean basal area tree. Here the whole crop is treated as one unit. Arithmatic mean tree is the tree having the diameter (or as near to it as possible) corresponding to the average basal area of the crops. Volume of this tree is found out by the formula

$$V = \frac{v \times S}{s}$$

where V is the total volume of wood as a whole.
v is the volume of the arithmatic mean tree (and not that of diameter classes)

s the basal area of arithmatic mean tree
S Total basal area.

In other words, the volume of the arithmatic mean tree multiplied by the total number of trees will give the volume of the crop.

Illustration

Please see the illustration of method 1. First part of the procedure upto filling up of col. 1 and 2 is th same. Basal area of mean tree of the plot is found by dividing the total basal area of the plot by the total number of trees.

i.e. $\frac{194.08}{225} = 0.8625$ Sft.

which is entered in col.3 The equivalent diameter for this basal area is 12.6 inches. This is entered in col.1. The trees with this nearest diameter are selected and entered in col.5 and their volume calculated and given in col.6.

No. of trees	Basal area in Sft. S.	Mean Tree		Sample trees			Total volume Cft. V = vxS/s
		Basal area in Sft S	Diameter in inches	Diameter in inches	Basal area in Sft s	Volume Cft v	
1	2	3	4	5	6	7	8
				12.1	0.799	22.40	
				13.1	0.936	25.93	5406 Cft.
225	194.08	0.8625	12.6		1.735	48.33	

$$V = \frac{v \times S}{s} = \frac{48.33 \times 194.08}{1.735}$$

$$= 5406 \text{ Cft.}$$

Merits: Simple and easily applicable. Only less number of sample trees have to be measured than method I.

Demerits: Accuracy is comparatively less. This method presupposes that the arithmatic mean basal area trees has the mean volume of the stand. But this may not always be correct as volume depends upon the height and form factor. Sometimes a tree of mean basal area may not be available in the area.

7.3 Other methods: Following are the other methods with different methods of grouping.

a) Huber's method: The mean diameter corresponding to average basal area for each group is found out and then sample trees are selected and measured for each group. Then volume is calculated as explained already.

b) Urich's method: In this method, groups are formed containing the same number of trees and the same number of sample trees for each group are selected. Volume can be found out by using the formula

$$V = \frac{\text{Total volume of sample trees} \times \text{Total Basal Area of woods}}{\text{Total Basal area of sample Trees}}$$

c) Hartig's method: He wanted that each group should have equal volume. As it is difficult to find out volume in the initial stage, the grouping was done so that each group had more or less the same, basal area. Then mean basal area was calculated and 2 sample trees from each group which had the mean basal area (or nearest to the basal area) were selected for measurement and computation.

d) Block's method: He gave preference for bigger trees as most of the smaller trees will be removed during thinning. Hence he placed largest trees in the first group and then brought the smaller trees in descending order. Then mean basal area was calculated for each group. Sample trees were selected which had this mean basal area for each group and then volume will be computed.

Since the above methods are not in our syllabus, we need not study them in detail.

8.1 Abstract Sample Tree methods: Method I and II required selection of concrete sample trees. We assumed that mean basal area will be the mean volume tree. This assumption is not always correct. Selection of concrete sample trees involves personal bias. Accuracy is only accidental. Hence it was proposed to take sample trees from small groups to be formed in the crop. This increased the number of sample trees. It was hoped that the abnormalities of one sample tree may get neutralized by some other trees.

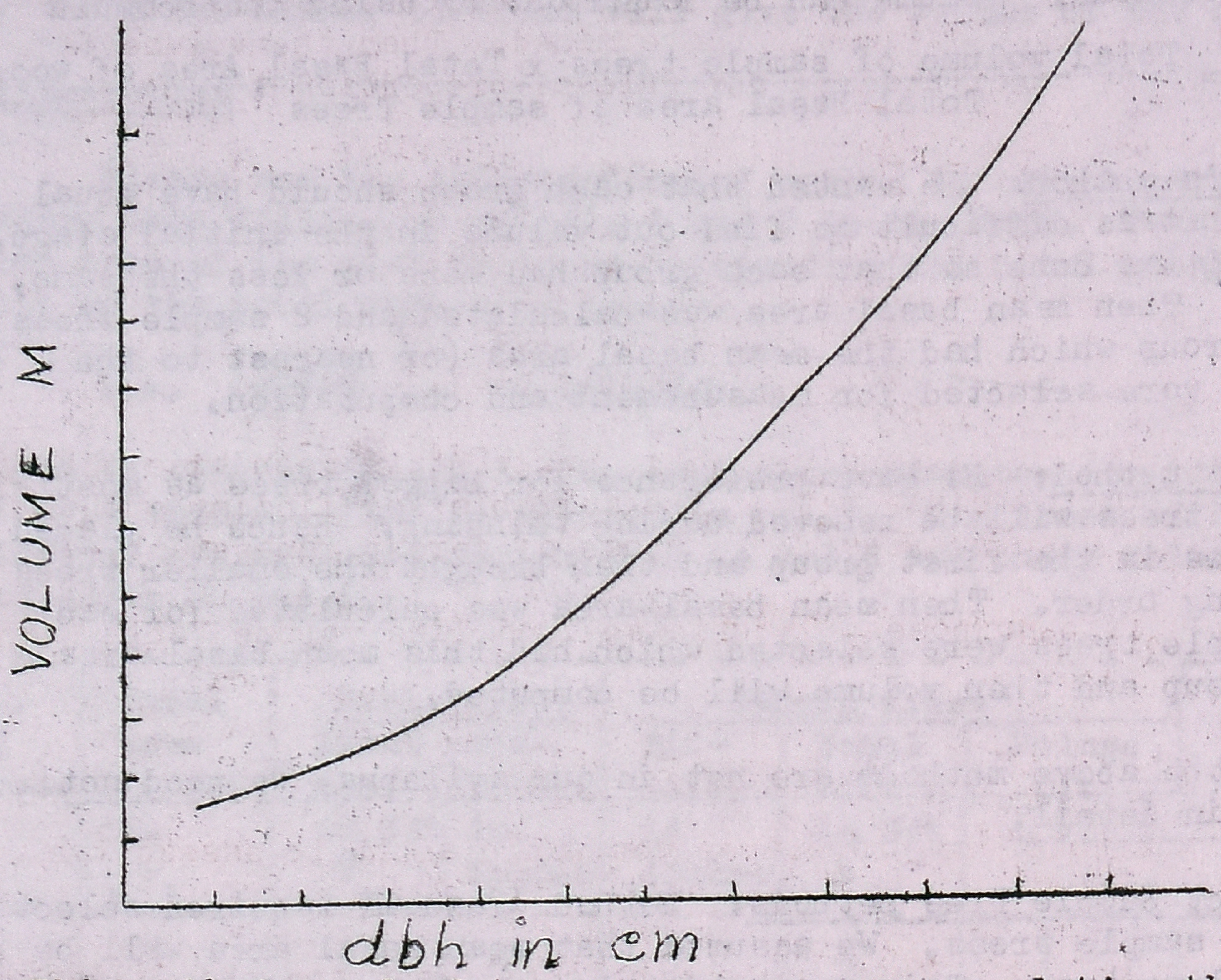
Following are few methods using Abstract Sample Trees:

8.2 Volume Table method: A volume table is based on the measurement of volumes of very large number of trees of different diameters and heights. Hence the volume given by a volume table for any diameter represents a good average. But only local volume tables should be used. Otherwise, a diameter/height curve may be drawn on the basis of measurements of a number of trees by plotting heights against diameters. From this curve, height can be found out for the mean diameter of a group. This method can be used in conjunction with any method described earlier - but it will be best to use the one inch diameter class methods.

Merits: Use of volume table eliminates personal bias involved in the selection of concrete sample trees. It saves lot of time and money required for selection, felling and measurement of concrete sample trees.

8.3 Volume Curve method: The difficulty with Volume Table method is whether it is suitable for the particular locality. To overcome this, SPEIDEL suggested the construction of a volume curve on the basis of large number of trees felled for any purpose - taking care not to include suppressed trees. From the data of these trees, a smooth curve is drawn with diameter or girth in X axis and volume in y axis. Grouping may be done in any method, discussed earlier. The diameter of mean tree of each group is calculated. Its volume is read from the curve. This is multiplied by the number of trees of the group

to get the volume of the group. The volume of the stand may be got by adding the volume of these groups.



This method may lead to errors as we are correlating the breast height measurement and volume without giving weight to height and form factor. Further the curve should be properly drawn.

9. <u>Form Factor method or Prussian Institute method</u>: In view of the drawbacks of volume curve method, SCHWAPPACH suggested that instead of drawing volume curve, Diameter/Height and Diameter/Form factor curves should be drawn. The sample trees should be measured and data collected. In constructing Diameter/Form factor curve, Diameter will be in <u>x</u> axis and Form factor in <u>y</u> axis (vertical). Similarly, in Diameter/Height curve, diameter will be taken in <u>x</u> (horizontal) axis and height in <u>y</u> axis (ordinates).

The diameter of mean tree of each group is then calculated. Its height and form factor are read from the curves. Volume is calculated

V = s x h x f where
<u>s</u> is the basal area of mean tree;
<u>h</u> is the height of mean tree read from curve;
<u>f</u> is the form factor read from the curve.

The volume of the group is calculated by multiplying the volume of the mean tree by the number of trees in the group. The group volumes are added to give the volume of the sample plot or stand.

10. <u>Sample Plot Method</u>: Sample plot is a plot chosen as a representative of a larger area. We will study about this, in detail, in later chapter. A sample plot should be so selected that it is a true representative of the larger area with regard to quality and density. They should have a regular geometric shape so as to calculate their area easily and correctly.

After selecting sample area, the enumeration is done. Their volume is calculated by any of the methods described earlier. The volume of the sample plot is thus determined. Then the volume of the whole wood is calculated by the rule of proportion

$$V = \frac{A}{a} \times v \quad \text{where}$$

V = Volume of whole stand;
A = Area of whole wood;
a = Area of sample plot;
v = volume of sample plot.

11. Applicability of various methods: Arithmatic mean tree method and one inch diameter class method are suitable for finding out the growing stock of sample areas for purpose of forest management.

For scientific purposes, graphic methods like volume Table method may be used.

PROBLEMS

1. Explain in detail the procedures you would adopt to assess the volume of a forest.

2. What is Top height? What is crop height? What are the differences between them?

3. Write short notes on

   i) Top height
   ii) Crop height
   iii) Lorey's formula
   iv) One inch diameter class method
   v) Prussian Institute method

CHAPTER IX

AGE OF TREES AND WOODS

1. Object: It is quite essential to determine the age of the trees to know the time required by the trees to produce the particular volume or weight. Without knowing the age of the trees, it is not possible to know at which rate the wood capital is growing. It may not be possible to compare the financial results of forestry with comparable land uses like agriculture, horticulture, etc.

Scope: Age will have to be determined in the case of

i) single trees when standing or felled and
ii) whole woods of evenaged forest and unevenaged forest.

2. Determination of Age of Single Trees when standing: The age of single trees can be found in the following methods:

2.1 From existing records: In the case of trees raised artificially, there may be some records like plantation journal which may have the date of sowing or planting. This may give the age of the trees at any particular period. These records will also give information if there were heavy casualties and if so, when the replacement was done. If the area had been worked under natural regeneration, under simple coppice system the age can be calculated from the records of sale of the coupes, felling period, etc. In case the trees have come up under natural regeneration under selection system, the years of felling may not be so useful in finding out the age. But the difference between seedlings - felling and the year of estimating the age may give the age of the trees. This may not be as accurate as in the case of artificial regeneration. However, the age assessed will only be approximate as there will be replacement of casualties in Artificial regeneration and regeneration spreads gradually under natural regeneration.

2.2 From General Appearance: Trees grow by putting on layer after layer of conical shells of growth every year which results in the elongation of leading shoots and branches as well as the thickening of stem, thus bringing about an increase in the height and diameter and crown-width of the trees though the rate of growth tends to fall off more and more after middle age is reached. Further, increase in age brings about other morphological changes also in the trees. This can be observed only by experienced people. The age of the trees can be found out by ocular estimate taking the following into consideration:

a) Size of the stem: Thicker the stem, higher the age.

b) Taper of the stem: Younger trees will exhibit comparatively a greater degree of taper.

c) Size, form and shape of crown: Bigger crowns indicate higher age. Chir pines (*Pinus roxburghii*) has a conical crown in earlier ages and becomes rounded as tree grows older.

d) Colour and condition of bark changes with age: Older trees will have smooth and light coloured bark. But younger trees will have rough, fairly cracked and dark coloured bark as in the case of Sal (*Shorea robusta*).

This method requires great practice and experience. These conditions will change due to locality factors and site quality. In better site qualities and in more open areas, the growth is likely to be better than in denser stand of poor site quality.

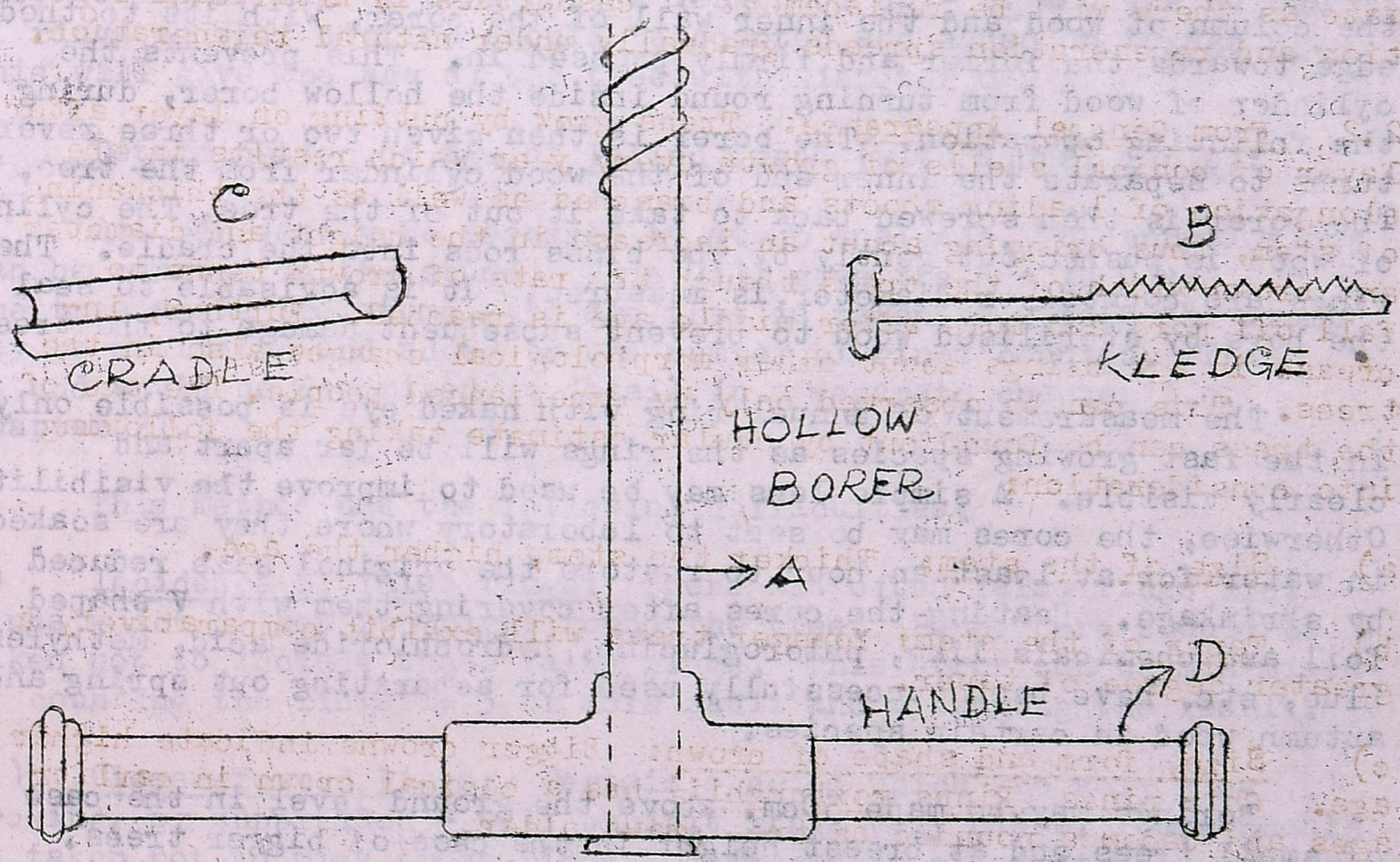
2.3 By the number of annual shoots or whorls of branches: Some species form only one whorl of branch per year. In such cases, the age of the tree can be assessed by counting the number of whorls from top downwards. Proportionate number of whorls may be added for that part in which these are not visible. This method is restricted to species like Blue pine, *Ceiba pentandra*, *Bombax ceiba*, etc.

3. Determination of Age of standing trees (with annual rings):

Introduction: Certain trees like *Tectona grandis*, *Acacia catechu* exhibit annual growth rings, whereas others do not exhibit the annual rings. Hence for such trees that have annualrings, following method can be used.

By the use of Pressler's Increment Borer:

3.2 Principle: The principle is the same as that of stump analysis, i.e., counting the number of annual rings on the radial cross section of the tree at the base. In the case of stump analysis, the number of annual rings on the surface cross section of the stump of a felled tree is counted and the age allowance for the tree to attain stump height is added - to find out the age of the tree. But under this method, a narrow cylinder of wood extending radially from the pith to the periphery is taken out by means of the Pressler's Borer and the number of rings on it is counted, as in the case of stump analysis. The advantage is that the tree need not be felled.



3.3 Description of Instrument:

i) A hollow borer 'A' which is slightly tapering from the handle and towards the point, the portion just behind the point being spiralised to facilitate its being screwed into the tree.

ii) A wedge 'B' on one side of which is marked a scale to measure the width of the concentric rings the other side being roughly toothed to enable extraction of the cylinder of wood. The instrument has also been provided with a brass rod of 2mm diameter to dislodge the cylinder of wood which sometimes gets stuck into the wedge.

iii) A cradle 'C' for keeping the extracted cylinder of wood without its breaking.

iv) A handle 'D' into which the borer 'A' has to be fitted before working it into the tree. The handle also is made hollow so that the borer, wedge and the cradle can be kept in it when the instrument is not in use.

The instrument is available in different lengths upto 40cm and can be used with ease in soft wood species.

3.4 Using the Instrument: The hollow borer wedge, cradle and brass rod are all taken out of the hollow handle. The borer is inserted in the central square hole of the handle from side opposite to which there is an iron clamp. The borer is held firm in the handle when it is clamped, as the clamp fits in the grove of the projecting hollow borer. After clamping the borer in the handle, the instrument is screwed in a radial direction into the tree at right angle to its axis to the desired depth. This can be done by turning the handle. This forces into its interior, a cylinder of wood. Hence, a cylindrical column of wood enters the hollow borer and is severed from the tree from all sides except at its base. Then the wedge is inserted between the column of wood and the inner wall of the borer, with its toothed edge towards the former and firmly pressed in. This prevents the cylinder of wood from turning round inside the hollow borer, during the following operation. The borer is then given two or three reverse turns to separate the inner end of the wood cylinder from the tree. The borer is then screwed back to take it out of the tree. The cylinder of wood is pushed out gently by the brass rods into the cradle. The rings are counted or diameter is measured. It is advisable to seal the bore by sterilised wood to prevent subsequent damage to the tree.

The measurement of annual ring with naked eye is possible only in the fast growing species as the rings will be far apart and clearly visible. A simple lens may be used to improve the visibility. Otherwise, the cores may be sent to laboratory where they are soaked in water for at least an hour to restore the original size reduced by shrinkage. Heating the cores after covering them with V shaped foil and chemicals like, phlorcglucine, hydrochloride acid, Methylene blue, etc. have been successfully used for separating out spring and autumn wood in certain species.

Borings may be made 30cm. above the ground level in the case of small trees and at breast height in the case of bigger trees.

3.5 Limitations of the Instrument:

1) Can be used to species which show distinct annual rings.

2) It is available in lengths upto 40cm. Hence cannot be used in the case of trees of more than 40cm. diameter.

3) As the pith is not always in the centre more than one boring may be necessary.

4) Ordinary make instruments can be used for soft woods only. Specially made instruments with special type of lever (German make) whose tip is fitted with thread one third in width of the ordinary borer should be used for hard woods. Power driven augers are also used in some countries.

3.6 Assessment of Age: The age corresponding to the height at which boring is done has to be added to the ring count to get the age of the tree. In case of bigger trees which cannot be bored upto the pith, borings can be restricted to 5 or 10 rings and the diameter for 5 or 10 years age is obtained by deducting twice the width of 5 or 10 rings from the present diameter. Then the methods adopted to find out the age of " trees without annual rings " should be adopted.

There is another method to find out the age of bigger trees. Select the biggest possible tree whose pith can be reached by the borer. Borings may be done in a number of such trees of the same diameter and the results of the age counts averaged to get the corresponding age. Let d1 be the diameter and a1 be the corresponding age. If the age of a bigger tree having a diameter of d2 has to be found out, boring should be done upto a length of d2 - d1 and the number of rings on this section should be counted and added on to age a1. This will give the age of the tree with diameter d2.

4. Determination of Age of Felled Trees (with annual rings):

Age can easily be assessed by stump analysis. The annual rings can be counted on the stump. This will give the age in years for the tree above the stump. The age that is taken to attain the stump may be estimated and added to the number of rings counted. This method would be described in detail in a separate chapter i.e. Chapter XI.

This method has the following difficulties:

i) Incidence of false rings: There are often false rings i.e. rings which do not run right round the tree. Hence care should be taken not to include these false rings. This error can be minimised by counting the rings in 3 or more radii and averaging the result.

ii) Closed-formed Rings: Certain species which are very slow growing, or suppressed - will exhibit rings very close. Care should be taken not to miss those rings. This can be eliminated by taking an oblique section for counting rings though the standard practice is to count the rings on a horizontal plane.

iii) Absence of Growth Ring in certain years: When the tree is subjected to defoliator attack or occurence of fire, frost, etc., rings may not be formed.

In spite of these difficulties this is the best and quickest method of determining the age of a tree.

Determination of Age of Trees without Annual Rings:

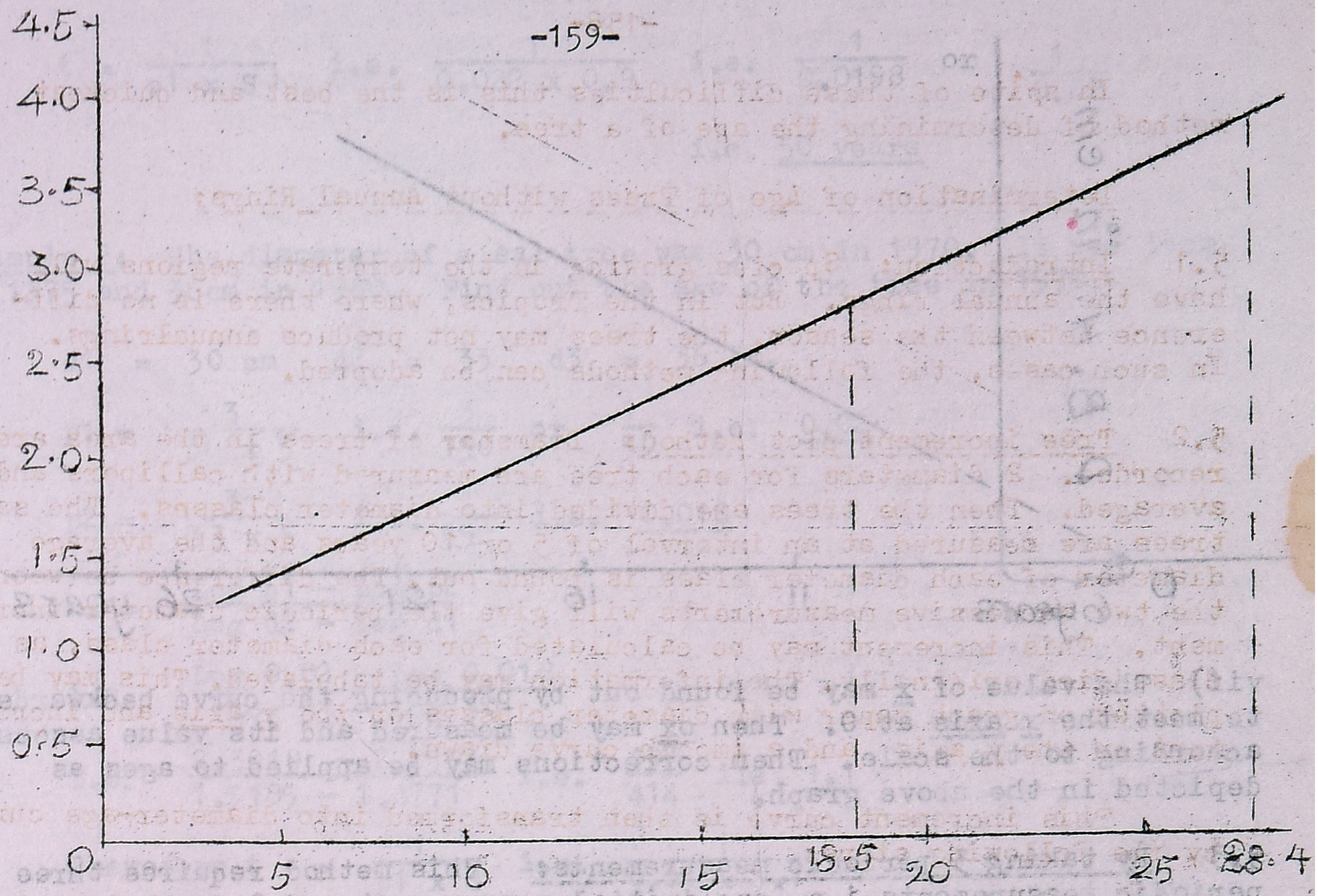
5.1 Introduction: Species growing in the temperate regions will have the annual rings. But in the Tropics, where there is no difference between the season, the trees may not produce annualrings. In such cases, the following methods can be adopted.

5.2 Tree increment plot method: Diameter of trees in the area are recorded. 2 diameters for each tree are measured with callipers and averaged. Then the trees are divided into diameter classes. The same trees are measured at an interval of 5 or 10 years and the average diameter of each diameter class is found out. The difference between the two successive measurements will give the periodic diameter increment. This increment may be calculated for each diameter class, as classified originally. The information may be tabulated. This may be plotted on graph paper with diameter classes on the x axis and increment on the y axis and a smooth curve drawn.

This increment curve is then transformed into diameter-age curve by the following steps:

Diameter class	Tree No.	Average D.B.H. O.B. in 1980	D.B.H. (O.B.) in 1985 D.B.H.	Average	Increment in diameter in cm after 5 years
10-20	1	16.0	18.0/19.0	18.5	18.5 - 16.0 = 2.5
	2	15.0	17.6/18.0	17.8	17.8 - 15.0 = 2.8
	3	15.7	17.9/18.7	18.3	18.3 - 15.7 = 2.6
		Total	..	54.6	7.9
		Average	..	18.2	2.63
20 - 30	1	26.0	28.5/29.5	29.0	29.0 - 26.0 = 3.0
	2	25.0	28.2/28.6	28.4	28.4 - 25.0 = 3.4
	3	24.0	27.6/28.0	27.8	27.8 - 24.0 = 3.8
		Total	..	85.2	10.2
		Average	..	28.4	3.4

(P.T.O.)



i) The lowest diameter on the increment curve is taken and its increment is read off directly from the curve. In the illustrated case, the lowest diameter, is 18.0 cm. Its increment is read from the curve. This is 2.5cm. This is added to the lowest diameter (original diameter) to obtain the final diameter at the end of 5 years.

ii) In this case let $\underline{x}$ be the age at which the diameter is 18.0cm. The diameter at x + 5 years will be 18.0 + 2.5 = 20.5 cm.

iii) Now find out the increment for this 20.5 cm from the curve. Let it be 3.0 cm. Its corresponding diameter at x + 10 years will be 20.5 + 3.0 = 23.5 cm.

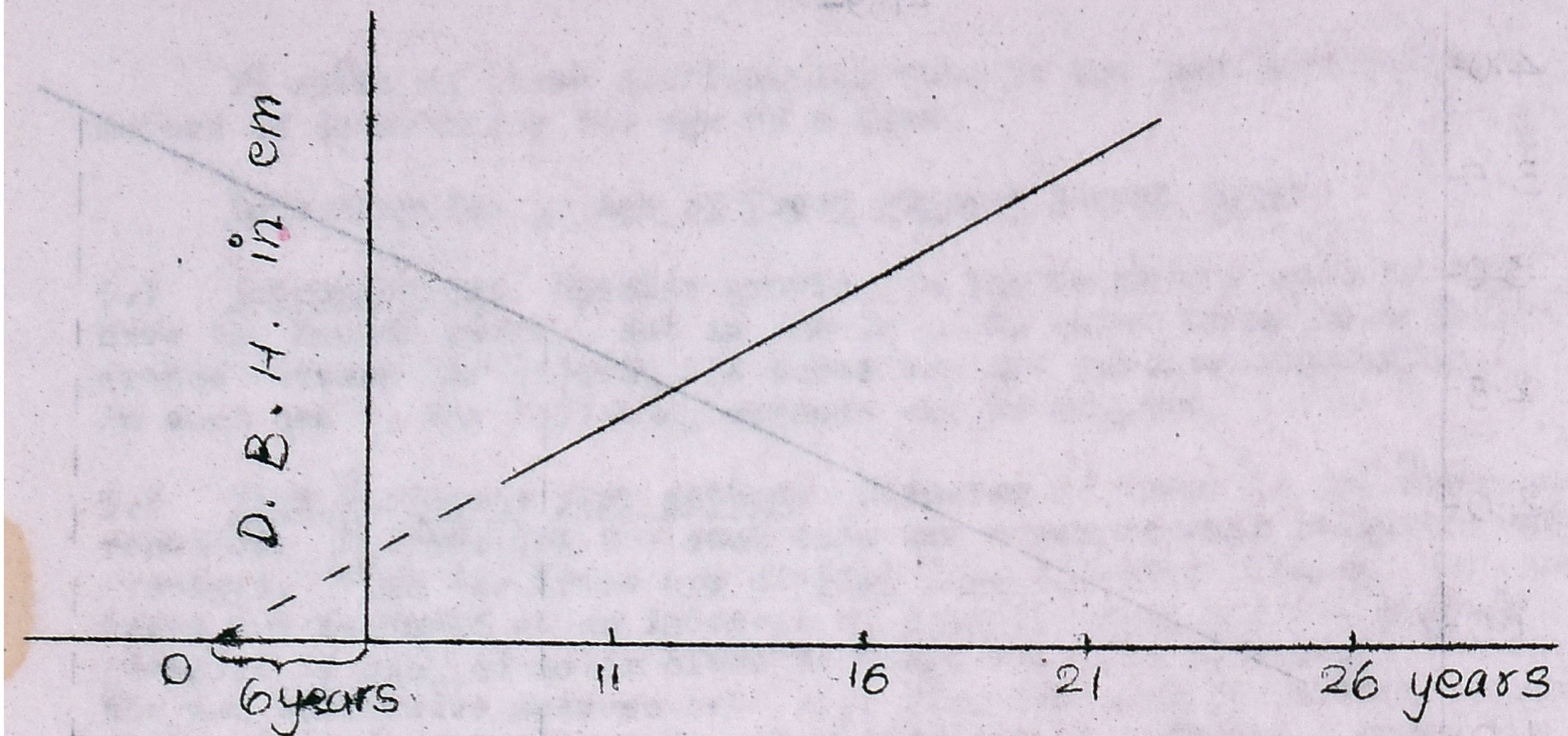
iv) Now find out the increment for 23.5 cm. Let it be 3.2 cm. Its corresponding diameter at x + 15 years will be 23.5 + 3.2 = 26.7 cm.

v) In this manner, diameters may be worked out for a series of age intervals of 5 years and tabulated as follows:

Years	Diameter cm
x + 5	20.5 cm
x + 10	23.5 cm
x + 15	26.7 cm

vi) This can be plotted in a graph paper to a smooth curve with d.b.h. in y axis and age series in x axis.

(see the curve in the next page)



vii) The value of x may be found out by producing the curve backwards to meet the x axis at O. Then ox may be measured and its value assessed according to the scale. Then corrections may be applied to ages as depicted in the above graph.

5.3 By taking 3 periodic measurements: This method requires three periodic measurements i.e. one initial measurement and 2 further measurements.

Let d1 be the diameter of the tree.
Let d2 and d3 be diameter at subsequent periodic measurements. Let p1 be the growth per unit diameter per year during two periodic measurements. Let p2 be the growth per unit diameter per year, during the period between 2nd and third periodic measurements.

The age of the tree can be found out by the following formula:

Let T be the age
Age T = 1/p1S where S is a constant which can be found out by the formula

$$S = \frac{\text{Log } p1 - \text{Log } p2}{\text{Log } d2 - \text{Log } d1}$$

Example 1: If the diameter of an oak tree in 1911 was 5'4" and in 1916 it was 6.0" and in 1921 it was 6'6" find out its age in 1911.

$$p1 \text{ after 5 years} = \frac{0.6}{5.4 \times 5} = 0.022$$

$$p^2 = \frac{0.6}{6.0 \times 5} = 0.02$$

$$S = \frac{\text{Log } p1 - \text{Log } p2}{\text{Log } d2 - \text{Log } d1}$$

$$\text{i.e.} \quad \frac{\text{Log } 0.022 - \text{Log } 0.02}{\text{Log} - 6.0 - \text{Log } 5.4}$$

$$\text{i.e.} \quad \frac{\bar{2}.8424 - \bar{2}.8010}{0.7782 - 0.7324} = \frac{414}{458} = \underline{\underline{0.9}}$$

$$t = \frac{1}{p1 \times S} \quad \text{i.e.} \quad \frac{1}{0.022 \times 0.9} \quad \text{i.e.} \quad \frac{1}{0.0198} \quad \text{or} \quad \frac{1}{0.02}$$

i.e. <u>50 years</u>

<u>Example 2</u>: The diameter of a sal tree was 30 cm in 1970. It was 33cm in 1975 and 36cm in 1980. Find out the age of the tree in 1970.

d1 = 30 cm   d2 = 33   d3 = 36 cm.

$$p1 = \frac{3}{30 \times 5} \quad \text{i.e.} \quad \frac{3}{150} \quad \text{or} \quad \frac{1}{50} \quad \text{i.e.} \quad \underline{0.02}$$

$$p2 = \frac{3}{33 \times 5} \quad \text{i.e.} \quad \frac{1}{55} \quad \text{i.e.} \quad \underline{0.018}$$

$$s = \frac{\text{Log } p1 - \text{Log } p2}{\text{Log } d2 - \text{Log } d1}$$

$$\text{i.e.} \quad \frac{\text{Log } 0.02 - \text{Log } 0.018}{\text{Log } 33 - \text{Log } 30}$$

$$\text{i.e.} \quad \frac{\bar{2}.3010 - \bar{2}.2553}{1.5185 - 1.4771} \quad \text{i.e.} \quad \frac{457}{414} \quad \text{i.e.} \quad \underline{1.1}$$

$$\text{Therefore } t = \frac{1}{p1 \times S} \quad \text{i.e.} \quad \frac{1}{0.02 \times 1.1}$$

$$\text{i.e.} \quad \frac{1}{0.022} \quad \text{i.e.} \quad \frac{1000}{22} \quad \text{i.e.} \quad \underline{45.5 \text{ years}}.$$

6. <u>Determination of Age of Woods</u>:

6.1 <u>Difference between Physical and Economical Ages</u>: Physical age is synonymous to the actual age - counted from the time it came into existence. But economical age consists of that period, in the life of the tree, during which it has actually been growing. This excludes the effective period during which it did not grow due to adverse factors like defoliation, suppression, old age, etc. The criterian for determining the economic age is the dimensions attained by the trees growing under normal conditions in the same locality at various ages. For example the physical age of a tree growing under suppressed conditions may be 50 years. But its actual diameter may be equal to another tree of the same species occuring in the same locality which is only 30 years. The economic age of the suppressed tree in this case is only 30 years.

6.2 <u>Age of Woods</u>: Forest crops are classified into evenaged and unevenaged crops depending upon the variations in age of trees constituting a crop.

6.3 <u>Evenaged woods</u> are woods which consist of trees of approximately the same age - but difference upto 25% of the rotation age may be allowed in case where a crop is not harvested for 100 years or more. This allowance is necessary as whole woods are not established in the same year. Subsequent replacement is required in the case of artificial regeneration. In the case of natural regeneration, 2 or more seed years may be required to have a complete stocking. There may be considerable difference in ages in natural regeneration. But these differences are not likely to be seen, provided regeneration period adopted is short. Hence in silvicultural terminology, they are called as evenaged woods or evenaged crop.

6.4 Unevenaged woods: This term is applied to crops in which the individual stems vary widely in age - the range of difference will be usually more than 20 years. In the case of long rotation, this will consist of crops of more than 25% of the rotation age in long rotation crops.

6.5 Regular forests: A Regular forest is composed of evenaged woods.

6.6 Irregular forests: A forest composed of unevenaged forest is called irregular forests.

7. Determination of age of Evenaged Crops: The age of an evenaged crop is described by the term crop age. Crop age is defined as the age of a regular crop corresponding to the crop diameter. Hence if the crop is of the same age say - a plantation, or crops raised under uniform system, crop age is the age corresponding to the age of the tree of mean diameter. In such cases, the age of a single tree can be determined either by felling the tree if the tree produces annual rings or by reading the age corresponding to the crop diameter from the age diameter curve - or by other methods discussed already.

But if there is much of differences, one of the following methods can be adopted:

7.1 Method 1: If there is not much difference in the age of the crop (i.e., range of age variation is limited) the rate of growth can be considered to be uniform. Hence mean age of the stand is taken to be equal to the age of the tree, having the volume equal to the average volume per tree of the stand. The mean tree is so selected that it will have the diameter equivalent to crop diameter (average diameter as derived from average basal area). Age of this selected tree is found out either by felling it and by analysing the age or by reading the age from age/crop diameter curves.

7.2 Method 2: If there is appreciable difference in ages of trees (as in unevenaged stand) the trees should be grouped into evenaged groups (age classes). Then the total basal area of each group can be found out. The age of this group is also found out, (by finding the age of a tree corresponding to the mean diameter as calculated from mean basal area). Then the following formula gives the crop age:

$$\text{Crop Age} = \frac{S1a1 + S2a2 + S3a3 + \ldots\ldots}{S1 + S2 + S3 + \ldots\ldots\ldots\ldots}$$

where S1, S2, S3 = basal areas of the evenaged groups;
a1, a2, a3 ......the ages of the evenaged groups.

But in practice it is very difficult to group the trees into age classes. Hence diameter classes should be taken instead of age classes. The total basal area and the average age of each diameter class will have to be ascertained before applying the formula.

Note 1: Top age is the age corresponding to the top diameter of a regular crop (i.e. the diameter as calculated from basal area of the 250 biggest diameters per Ha, two diameters having been taken while measuring each tree) as read from the age/diameter curve.

2: Crop Age: Generally crop age means mean age. But there is difference of opinion about the definition of mean age. The Indian Forest and Forest Products Terminology - Part I - Forests, defines mean age as the "average age of dominant

trees in a crop". But Schlich defined mean age of an unevenaged wood as " that period which an evenaged wood requires to produce the same volume as the unevenaged wood."

8. b) Determination of Age of Unevenaged Woods: Following are special variations of unevenaged woods.

A forest composed of unevenaged forest is known as Irregular Forests.

A selection forest is an unevenaged crop containing theoretically all age classes or gradations. This is a good example for irregular forests. Similarly the term " All Aged " is applied to an unevenaged crop in which theoretically all age gradations upto and including those of exploitable age are found.

An unevenaged wood contains trees of widely varying age and hence the age of the wood, as a whole, can only be the mean age. But according to Schlich, mean age is the economic age. Since there is difference of opinion about the mean age, several scientists have evolved several methods of determining the age of unevenaged woods. Let us see some of the methods.

8.1 Method 1: Smallian and C.Heyer's formula:

We know that $M.A.I. = \frac{Volume}{Age}$. Hence Age x MAI = Volume.

$$\text{Hence Age} = \frac{Volume}{M.A.I.}$$

Smallian and Heyers have taken this and defined mean age of unevenaged stand as the sum of the volume of the groups of different age classes divided by the sum of the M.A.Is. of these groups. Thus

$$\text{mean age} = \frac{V1 + V2 + V3 + \ldots\ldots\ldots\ldots Vn}{\frac{V1}{a1} + \frac{V1}{a2} + \frac{V2}{a3} + \ldots\ldots\ldots\ldots \frac{Vn}{an}}$$

This is the formula.

Where V1, V2, V3 ....are the sum of volumes of evenaged groups

and a1, a2, a3 .....are the average ages of these groups.

Comments: The chief merit is that this is the most accurate method. The demerit is that it requires previous calculation of volume which is cumbersome.

8.2 Method 2: Modification of the method 1:

Above formula may be modified to overcome the defect. We know that volume depends upon the basal area. Hence the age can be correlated with basal area.

$$\text{Mean Age} = \frac{S1a1 + S2a2 + S3a3 + \ldots\ldots}{S}$$

Where S1, S2, S3 .....are the total basal areas of evenaged groups.

a1, a2, a3 ....are the average ages of these groups;
S is the total basal area of the whole forests.

Comments: This modified version is practically more simple and easy to apply and it works well if form-heights of the diameter classes are equal.

8.3 Method 3: Andre's Formula: A less dependable method is to substitute the number of trees for the basal area in each age or diameter class.

$$\text{Mean Age} = \frac{n1a1 + n2a2 + n3a3 + \ldots\ldots}{n1 + n2 + n3 + \ldots\ldots}$$

Where n1, n2, n3 ...are the number of trees in a1, a2, a3 age classes;

a1, a2, a3 ...are the average ages of evenaged groups.

Comments: This formula will give fairly accurate result. But it is difficult to find the number of trees in each age class.

8.4 Method 4: Gumpel's formula: If the evenaged groups occupy distinct areas, the area occupied by each age class may be used to determine the mean age. Thus mean age

$$\frac{m1a1 + m2a2 + m3\ a3 + \ldots\ldots\ldots}{m1 + m2 + m3 + \ldots\ldots}$$

Where m1, m2, m3 ...are the areas occupied by different age classes and

a1, a2, a3 ...are the average ages of these classes.

Comments: This can be applied only if the various age classes occupy the distinct areas. This may not happen in practice. This may give fairly accurate result if the range of age class adopted is not wide.

8.5 Method 5: Sample Tree method: This is the easiest method. We must take the mean age as equal to the average age of the sample trees.

$$\text{Mean age} = \frac{a1 + a2 + a3 + \ldots\ldots}{n}$$

where a1, a2, a3 ...are the ages of sample trees representing different age classes and n is the total number of sample trees.

Comments: This is practically very convenient. But it is not very accurate as various age classes are not found in the proper proportion. Following example will prove that this method is not accurate.

Data:	Age	Vol.	M.A.I.
	10	10	1
	100	2000	20

By Smallian and Heyer's formula,

$$A = \frac{2000 + 10}{\frac{2000}{100} + \frac{10}{10}} \quad \text{i.e.} \quad \frac{2010}{21} \quad \text{i.e.} \quad \underline{95.7}$$

According to Sample Tree method $A = \frac{100 + 10}{2} = \underline{55}$

This method can be improved by taking a larger number of sample trees in the higher diameter classes. Otherwise the number of sample trees representing a particular age class should be proportional to the volume of all the trees falling in that particular age class. This is also difficult as this requires a prior knowledge of volume of various age classes. Personal bias in selection of sample trees also play a key role.

9. A review of the above methods: Method 1 is theoretically the most accurate one and it can be used for testing the accuracy of other methods. Method 2 is a simple and practically more convenient method, than method 1. It can also be as accurate as method 1, provided the form heights of the various trees in a diameter group is the same. The drawback of last 3 methods is that they are based on purely arithmetic averages. As volume and its increment are the ultimate objective when determining the age, the mean age should always be weighed by volume or basal area and not by the number of trees or area of the age class.

PROBLEMS

1. Find the mean age of unevenaged wood with the following particulars by a) Smallian and Heyer's formula, b) Gumpel's formula c) Andre's formula and d) Sample tree method.

Volume of various age classes.	Average age of the group	Areas over which the various age classes are represented.	No. of trees in various age classes.
4000 m^3 V1	50 a1	2 Ha m1	n1 1500
9000 m^3 V2	60 a2	3 Ha m2	n2 1600
7000 m^3 V3	70 a3	2 Ha m3	n3 800
4000 m^3 V4	80 a4	1 Ha m4	n4 300

Solution:

a) Smallian and Heyer's formula:

$$\text{Mean age} = \frac{V1 + V2 + V3 + \dots\dots\dots}{\frac{V1}{a1} + \frac{V2}{a2} + \frac{V3}{a3} + \dots\dots\dots}$$

where V1, V2, V3 are the sum of volumes of evenaged group,

a1, a2, a3 ...are the average ages of the group.

$$\text{Hence mean age} = \frac{4000 + 9000 + 7000 + 4000}{\frac{4000}{50} + \frac{9000}{60} + \frac{7000}{70} + \frac{4000}{80}}$$

i.e. $\frac{20000}{80 + 150 + 100 + 50}$ i.e. $\frac{20000}{380}$ i.e. 63.2 years

b) Gumpel's formula:

$$\frac{m1\ a1 + m2\ a2 + m3\ a3 + \ldots\ldots\ldots}{m1 + m2 + m3 + \ldots\ldots\ldots\ldots}$$

i.e. $\frac{(2 \times 50) + (3 \times 60) + (2 \times 70) + (1 \times 80)}{2 + 3 + 2 + 1}$

i.e. $\frac{100 + 180 + 140 + 80}{8}$

i.e. $\frac{500}{8}$ i.e. 62.5 years.

c) Andre's formula:

$$\frac{n1a1 + n2a2 + n3a3 + \ldots\ldots\ldots}{n1 + n2 + n3 + \ldots\ldots\ldots}$$

i.e. $\frac{(1500 \times 50) + (1600 \times 60) + (800 \times 70) + (300 \times 80)}{1500 + 1600 + 800 + 300}$

i.e. $\frac{75000 + 96000 + 56000 + 24000}{4200}$

i.e. $\frac{251000}{4200}$

i.e. $\frac{2510}{42}$ i.e. 59.8 years.

d) Sample Tree Method:

Mean age $= \frac{a1 + a2 + a3 + \ldots\ldots}{n}$

i.e. $\frac{50 + 60 + 70 + 80}{4}$

i.e. $\frac{260}{4} = 65$ years.

2. Find the mean age of unevenaged wood with the following particulars by a) Smallian's and Heyer's formula; b) Gumpel's formula; c) Andre's formula and d) Sample tree method.

Volume of various age classes	Average ages of the group	Area over which the various age classes are represented.	No. of trees in various age classes
5000 m^2 V_1	50 yrs. a1	5 Ha. m1	1200 n1
8000 m^3 V_2	60 yrs. a2	4 Ha. m2	1500 n2
6000 m^3 V_3	70 yrs. a3	2 Ha. m3	800 n3
9000 m^3 V_4	80 yrs. a4	3 Ha. m4	500 n4

Note: Notations have been given in both problems for the guidance of students.

a) Smallian and Heyer's formula:

$$\text{Mean age} = \frac{V1 + V2 + V3 + \dots\dots\dots}{\frac{V1}{a1} + \frac{V2}{a2} + \frac{V3}{a3} + \dots\dots\dots}$$

$$= \frac{5000 + 8000 + 6000 + 9000}{\frac{5000}{50} + \frac{8000}{60} + \frac{6000}{70} + \frac{9000}{80}}$$

$$= \frac{28000}{100 + 133 + 86 + 112} = \frac{28000}{431} = 65 \text{ years.}$$

b) Gumpel's formula:

$$\frac{m1a1 + m2a2 + m3a3 + \dots\dots\dots}{m1 + m2 + m3 + \dots\dots}$$

$$= \frac{(5 \times 50) + (4 \times 60) + (2 \times 70) + (3 \times 80)}{5 + 4 + 2 + 3}$$

$$= \frac{250 + 240 + 140 + 240}{14} = \frac{870}{14} = 62 \text{ years.}$$

c) Andre's formula:

$$\text{Age} = \frac{n1a1 + n2a2 + n3\ a3 + \dots\dots\dots}{n1 + n2 + n3 + \dots}$$

$$= \frac{(1200 \times 50) + (1500 \times 60) + (800 \times 70) + (500 \times 80)}{1200 + 1500 + 800 + 500}$$

$$= \frac{60000 + 90000 + 56000 + 40000}{4000}$$

$$= \frac{246000}{4000} = 61.5$$

d) Sample Tree method:

$$\text{Age} = \frac{a1 + a2 + a3 + \dots\dots}{n}$$

$$\frac{50 + 60 + 70 + 90}{4} = \frac{260}{4} = 65 \text{ years}$$

PROBLEMS

3) How will you assess the age of woods of trees which do not have annual rings?

4) Describe Pressler's Borer. How will you use it for assessing the age of trees? What are the limitations of the instrument?

CHAPTER X

INCREMENT OF TREES AND WOODS

1. Introduction: Trees grow by putting on conical shells or wood during the growing season. Linear growth takes place as the result of the direct activity of the original tissue or primary meristem. Subsequent radial growth is brought about by division and enlargement of secondary meristem, or cambium, which produces new wood and bark between the old wood and bark. We do not give much importance for root growth in forestry though root portion is important in certain trees like Santalum album. The radial growth and height growth of stem, together with the resulting changes in the stem form have to be measured for determining the volume of a tree. Fluctuations of growth occur daily and seasonally. But daily variations cannot be generally measured in trees. But seasonal variation is important as they areresponsible for the formation of growth rings. The spring wood is lighter and more porous while summer wood is darker and denser. Thus the annual growth of a tree, in a cross-section of the stem, will form a pattern of concentric rings. The annual radial growth of tree can be found out by measuring the width of these rings. But the radial growth is not the same along the entire length of the stem. The height and radial growth do not start and end at the same time. In most of the tree species, height growth starts and culminates earlier than the radial growth.

Tropical species and some broad leaved trees in temperate climates (except a few species) do not generally form annual rings. Acacia catachu and Tectona grandis are examples of broad-leaved tropical species which show annual growth rings. Some other species like Boswellia serrata show growth rings but they are not annual. In some species several rings may be produced in a year whereas in some other species one ring may be formed after several years.

Hence, during every season, a tree increases by elongation of the top shoot, side branches, roots and by laying layers of wood and bark, whether distinctly visible or not. Thus diameter, height as well as spread of the crown increase consistently upto a certain age, producing an increase in biomass or volume. But we generally measure only those parts of trees that are above ground.

2.1 Definition of increment: Increment is defined as the "increase in girth, diameter, basal area, height, volume, quality, price or value of trees or crops during a given period." Increment also denotes the rate of increment.

2.2 Rate of Increment: The rate at which a tree or crop increases with age is called the rate of increment and may relate to any of the variables, i.e., diameter, girth, height, volume, etc. and is expressed usually as so much per year.

3. Classification of increment: The increment, whether in diameter, height or volume is classified as follows, depending upon the period to which it relates.

i) Current Annual Increment (CAI): is the increment put on by the tree or the crop in a specific year or single year. But it is usually used to denote the annual increment put on in a short preceding period - say 5 years since trees have slow rate of growth, or the Periodic Annual Increment i.e. PAI or PMAI.

ii) Periodic Annual Increment is the average annual increment for any short period.

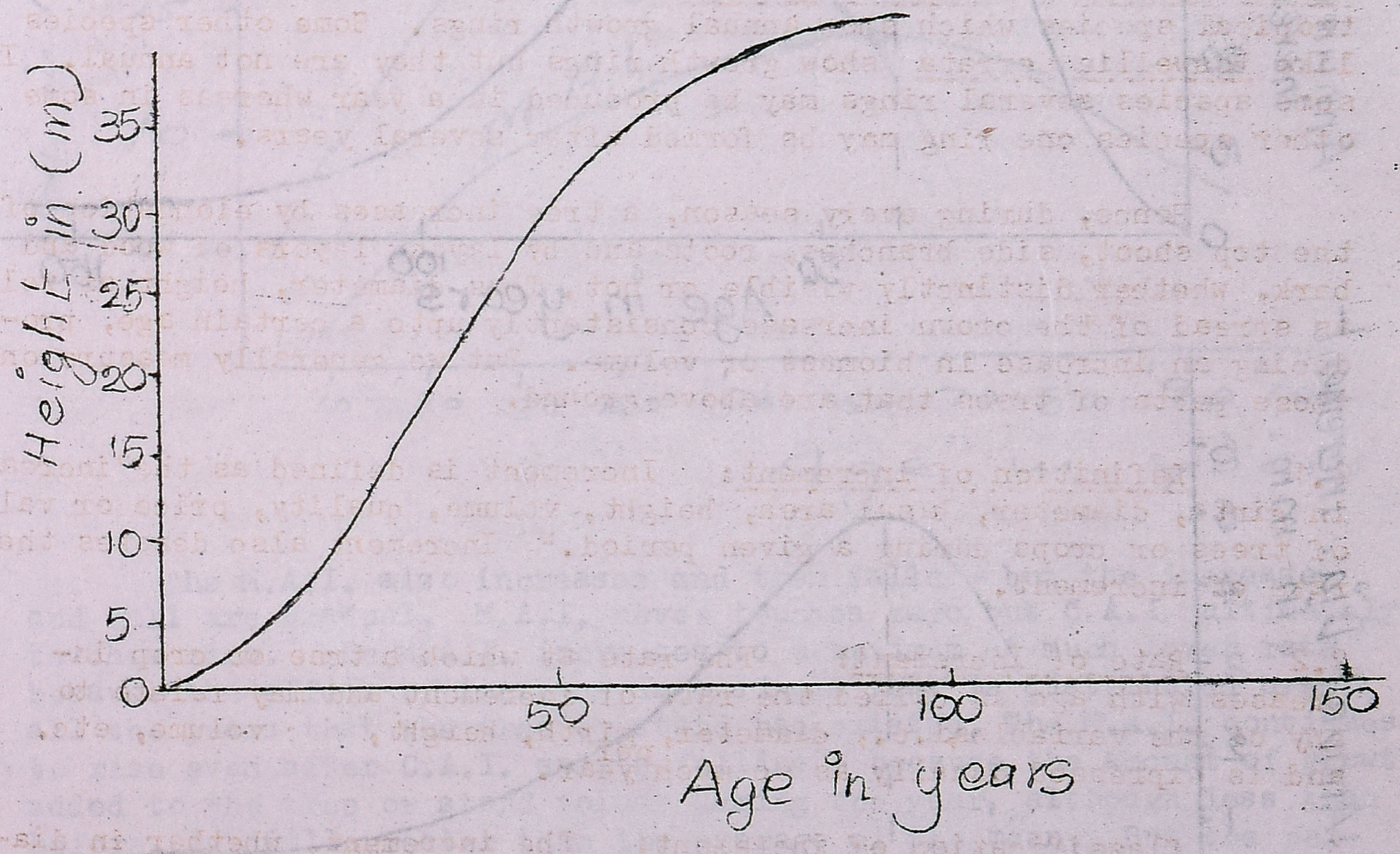
iii) Periodic Increment is the increment put on by a tree or crop during a number of years.

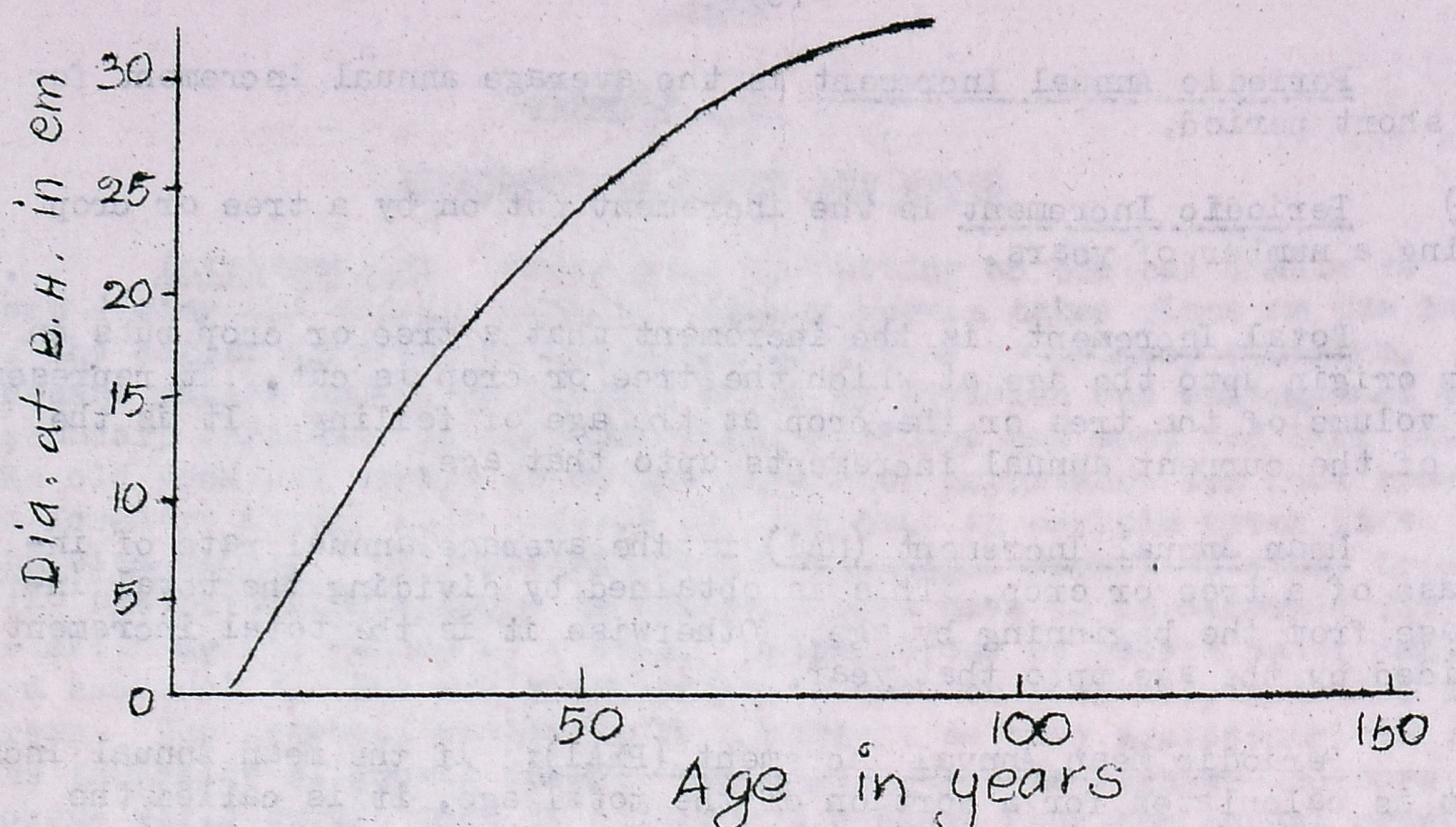
iv) Total Increment is the increment that a tree or crop puts on from origin upto the age at which the tree or crop is cut. It represents the volume of the tree or the crop at the age of felling. It is the sum of the current annual increments upto that age.

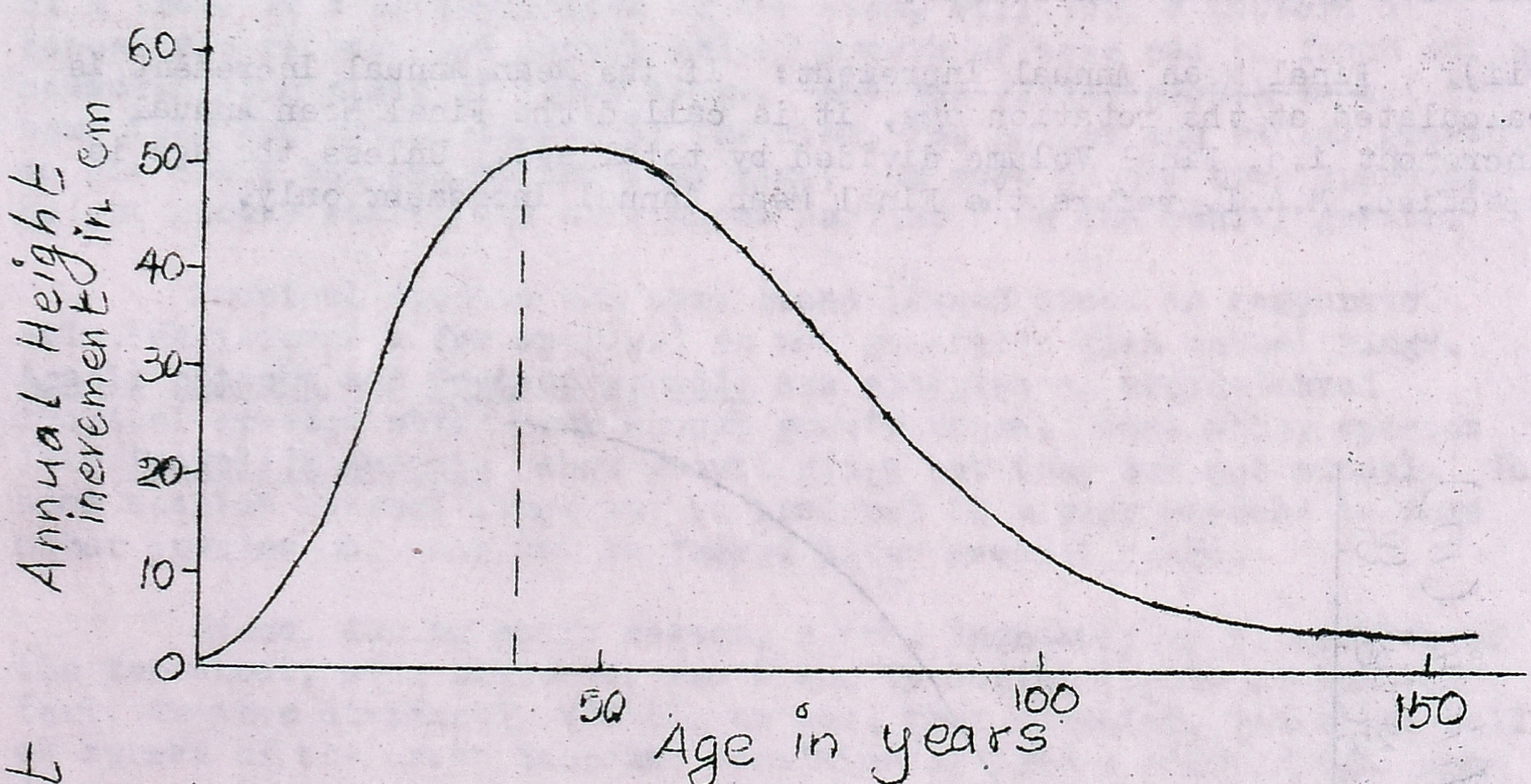
v) Mean Annual Increment (MAI) is the average annual rate of increase of a tree or crop. This is obtained by dividing the total increase from the beginning by age. Otherwise it is the total increment divided by the age upto that year.

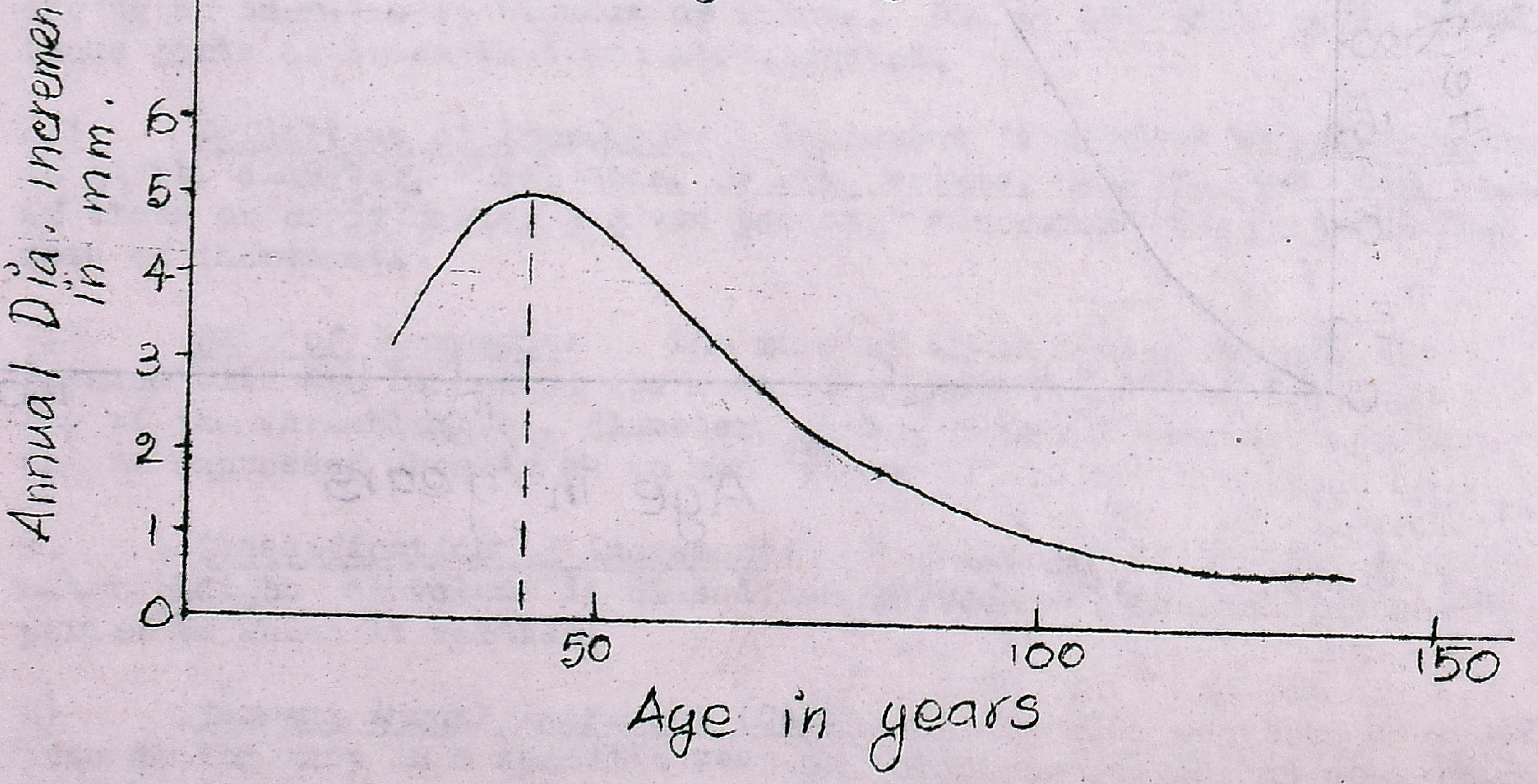
vi) Periodic Mean Annual Increment (PMAI): If the mean Annual Increment is calculated for a portion of the total age, it is called the Periodic Mean AnnualIncrement.

vii) Final Mean Annual Increment: If the Mean Annual Increment is calculated at the rotation age, it is called the Final Mean Annual Increment i.e. Final Volume divided by total age. Unless the age is specified, M.A.I. refers the Final Mean Annual Increment only.




Dia. at B.H. in cm
30
25
20
15
10
5
0
50
100
150
Age in years

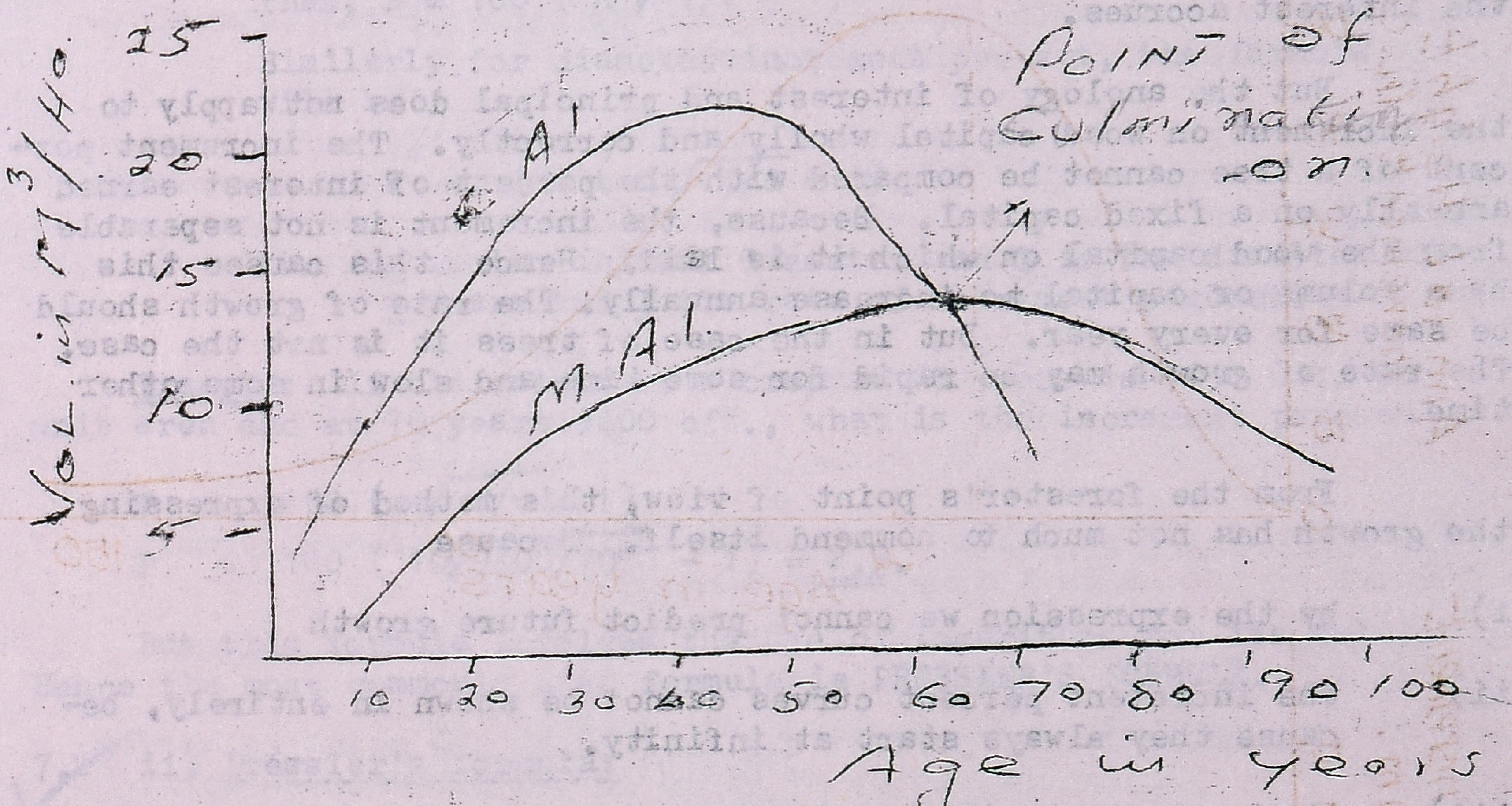

Annual Height increment in cm
60
50
40
30
20
10
0
50
100
150
Age in years


Annual Dia. increment in mm.
6
5
4
3
2
1
0
50
100
150
Age in years

4. Negative Increment: Trees grow slowly in the beginning and then grow more rapidly upto a certain age. It reaches an optimum level. After that the rate of growth slows down. The age at which highest growth is reached is different for different growth parameters i.e. diameter, height, form, volume, etc. The growth actually is never stopped until the death of the tree. But with increase in age, forces of decay become more active. Hence, rate of decay becomes more than the increment. At this stage, the tree is said to put on Negative Increment.

5. Relation between (CAI and MAI): The M.A.I. of a tree or a stand is the expession of average yearly response in the past to the growth factors of the site. But C.A.I. is the actual response in any one year. The two will never coincide except twice i.e. once at the end of the first year and second in the year of the culmination of the M.A.I.

The C.A.I. is not uniform throughoutthe life of the tree or stand. It rises to a maximum and then gradually falls off. The steepness of the rise may not be uniform throughout the period of rise. With some species like Pine, it is small to start with; then rises steeply to a climax and falls off. In either case, the falling off is not so steep as the rise.



The M.A.I. also increases and then falls - but the increase and fall are gradual. M.A.I. never touches zero but C.A.I. ultimately touches zero. The M.A.I. increases to a maximum at much lower rate because the effect of increase in a single year is distributed over all the years that the tree or stand had existed. The M.A.I. continues to rise even after C.A.I. starts falling - because the amount of growth added to the tree or stand volume during the year, although less than before, is still greater than the average of the mean. But the persistant decrease in the C.A.I. makes it fall to the level of M.A.I. and becomes equal to it. When graphed, this is portrayed by the intersection of the C.A.I. and M.A.I. curves and the point of intersection represents the culmination of the mean annual increment and thereafter also starts decreasing. Finally there will be no growth and C.A.I. will become zero. In some cases there will be not only

" No Growth " but losses - which will make the C.A.I. " negative ". The year of culmination of the M.A.I. - rather than the C.A.I. indicates the maturity of the stand. This means the crop has to be cut at this age to get the greatest average yield per year for the entire period of production. The curves of C.A.I. and MA.I cross each other at the maximum of M.A.I. curve. This is the age of maximum production and hence the crop or tree should be cut at this age.

6. Increment Percent is defined as the average annual growth in diameter, basal area or volume over a specified period - expressed as a percentage of diameter, basal area or volume - either at the beginning or more usually half way between the beginning and end of the periods.

This is a better way of expression of the rate of increment from the point of view of a businessman. A forester will tell that the tree has been growing in diameter, basal area or volume at a certain rate, during a certain period. This statement does not refer to the capital on which the increase is taking place. If the increase per year is expressed as a percentage of diameter or basal area or volume of the tree or crop to which it relates, it indicates the rate of growth, clearly and makes it comparable with other forms of investments on which the interest accrues.

But the anology of interest and principal does not apply to the increment on wood capital wholly and correctly. The increment percent of a tree cannot be compared with the percent of interest earned annually on a fixed capital. Because, the increment is not separable from the wood capital on which it is laid. Hence this causes this base volume or capital to increase annually. The rate of growth should be same for every year. But in the case of trees it is not the case. The rate of growth may be rapid for some time and slow in some other time.

From the forester's point of view, this method of expressing the growth has not much to commend itself. Because

i) by the expression we cannot predict future growth

ii) the increment percent curves cannot be shown in entirely, because they always start at infinity.

iii) the curves cannot be easily extended and so forecast of the future growth is difficult

iv) The actual growth for any one year becomes part of the capital on which the next year's growth percent is computed. Hence the value of increment percent figures are never constant and vary from year to year.

v) This problem becomes complicated as the rate of growth of trees vary from young age to old age.

vi) As the volume increases increment percent tends to decrease. Hence the increment percent, as at a given stage, when applied to forecast future yield is likely to result in over-estimation.

Increment percent is usually based upon a single year's growth. But usually one year's growth is not measured. We always measure once in 5 years or 10 years, so as to eliminate variable factors that affect a single season's growth caused by the climatic factors. Hence Periodic Mean Annual Increment is substituted for C.A.I. as a basis of computing growth or increment percent. The increment percent figure is not an index of absolute increase (in diameter basal area or volume) -- because it is merely the expression of a relation between the capital and increment existing at a given time.

7. Formulae for determining increment percent: The following are the formulae used for determining increment percent in diameter and volume:

7.1 Compound Interest Formula: The correct method of representing increment percent will be in terms of compound interest. The increment of diameter or volume in tree is like the increase in the capital at compound interest. Hence, the same formula is used.

Let v be the initial volume and V be the volume at the end of "n" years and P the rate of the increment percent (compound interest).

Then, $P = 100 \left(\sqrt[n]{V/v} - 1 \right)$

Similarly for diameter increment percent, the formula will be

$$P = 100 \left(\sqrt[n]{D/d} - 1 \right)$$

where d is the initial diameter and D is the diameter after n years and P the rate of increment percent.

Example: If the volume of a crop at 60 years is 7050 cft. per unit area and at 70 years 9400 cft., what is the increment percent?

$$P = 100 \left(\sqrt[n]{V/v} - 1 \right)$$

$$P = 100 \left(\sqrt[10]{9400/7050} - 1 \right) = 2.9.$$

But this formula involves the use of logarithms for its solution. Hence the most commonly used formula is PRESSLER'S FORMULA.

7.2 ii) Pressler's formula:

a) For Diameter Increment percent: Pressler calculated the increment percent by simple interest rate on the mean of the two diameters.

Let D be the Diameter after "n" years
d be the initial diameter
P the rate of increment percent
n the number of years in the period.

Formula is derived as follows:

Diameter at the mid point of the period or mean of the two diameters. $\left\} \dfrac{D + d}{2}\right.$

This is used as the base.

Annual increment during the period of "n" years. $\left\} \dfrac{D - d}{n}\right.$

Since the annual increase in diameter is on $\frac{D + d}{2}$,

$$\text{Increment percent} = \frac{\frac{D - d}{n}}{\frac{D + d}{2}} \times 100$$

$$\text{i.e. } \frac{D - d}{n} \times \frac{2}{D + d} \times 100 \quad \text{i.e. } \frac{200\,(D - d)}{n(D + d)}$$

b) <u>For Volume Increment Percent:</u>

Let V be the volume after n years.
v be the initial volume
P the increment percent

substituting V for d as in (a)

$$P = \frac{200\,(V - v)}{n(V + v)} \quad \text{or} \quad \frac{200}{n} \times \frac{V - v}{V + v}$$

The above formula can be generally applied for the determination of volume of the woods as a whole.

The height in case of trees past the middle age, will remain more or less constant. Height being the same, the form factor also being the same, the volume will differ based on the basal area or square of diameter. Hence Pressler's formula for volumes may be substituted by diameter.

$$P = \frac{200\,(D^2 - d^2)}{n(D^2 + d^2)} \quad \text{or} \quad \frac{200}{n} \times \frac{(D^2 - d^2)}{D^2 + d^2}$$

7.3 <u>Schneider's formula:</u> Schneider modified the above formula further to put it in a simplified manner.

$$P = \frac{400}{nD}$$

where D is the present d.b.h. (ub) at the point of boring
n is the number of rings in the outermost centimetre of the radius as ascertained by Pressler's Borer.

This formula can be used easily as it involves present diameter measurement and number of rings in the last one c.m. of radius. But this can be used only for such species which form annual rings.

8.0 <u>Problems</u>

8.1 <u>Examples:</u> 1) The diameter of a Teak tree measured in 1940 was 20cm and it was 40cm in 1950 what is the increment percent of i) diameter; ii) and volume?

i) Pressler's formula $= \frac{200\,(D - d)}{n(D + d)}$

In this problem D is 40cm, d = 20cm and n is 10 years.

$$\text{Hence } P = \frac{200\,(40 - 20)}{10(D + d)} \quad \text{i.e. } \frac{200 \times 20}{10 \times 60} = 6.6\%$$

ii) Volume Pressler's formula:

$$\frac{200\ (D^2 - d^2)}{n(D^2 + d^2)}$$

$$\text{Hence P} = \frac{200\ (40^2 - 20^2)}{10(40^2 + 20^2)}$$

$$\text{i.e.}\ \frac{200\ (1600 - 400)}{10(1600 + 400)}$$

$$\text{i.e.}\ \frac{200 \times 1200}{10 \times 2000} \quad \text{i.e.}\ \underline{12\%}$$

8.2 The diameter of a Sal tree was 30 cm. After 15 years it was 60 cm. What is the increment percent of i) Diameter ii) volume?

i) Diameter

Pressler's formula $= P = \frac{200\ (D - d)}{n\ (D + d)}$

Here D is 60cm, d is 30 cm and n = 15.

$$\text{Here P} = \frac{200\ (60 - 30)}{15\ (60 + 30)}$$

$$\text{i.e.}\ \frac{200 \times 30}{15 \times 90} \quad \text{i.e.}\ \frac{40}{9} \quad \text{i.e.}\ \underline{4.4\%}.$$

ii) Volume:

$$P = \frac{200\ (D^2 - d^2)}{n(D^2 + d^2)} \quad \text{i.e.}\ \frac{200\ (60^2 - 30^2)}{15(60^2 + 30^2)}$$

$$\text{i.e.}\ \frac{200\ (3600 - 900)}{15\ (3600 + 900)}$$

$$\text{i.e.}\ \frac{200 \times 2700}{15 \times 4500} = \underline{8\%\ \text{Ans}}.$$

8.3 Example 3: If the diameter of a given tree at a particular age of 70 years is 50cm and the number of rings in the last one cm of radius is 10, what is the increment percent?

Schneider's formula $P = \frac{400}{nD}$ i.e. $\frac{400}{10 \times 50} = \underline{0.8\%}$

8.4 Example 4: If the diameter of a tree is 40cm and the number of rings in the last one cm is 5 what is the increment percent?

$$\frac{400}{5 \times 40} = \underline{2\ \%\ \text{Ans}}.$$

9.0 Determination of the Increment of Single Trees:

9.1 Height Increment:

a) of the past:

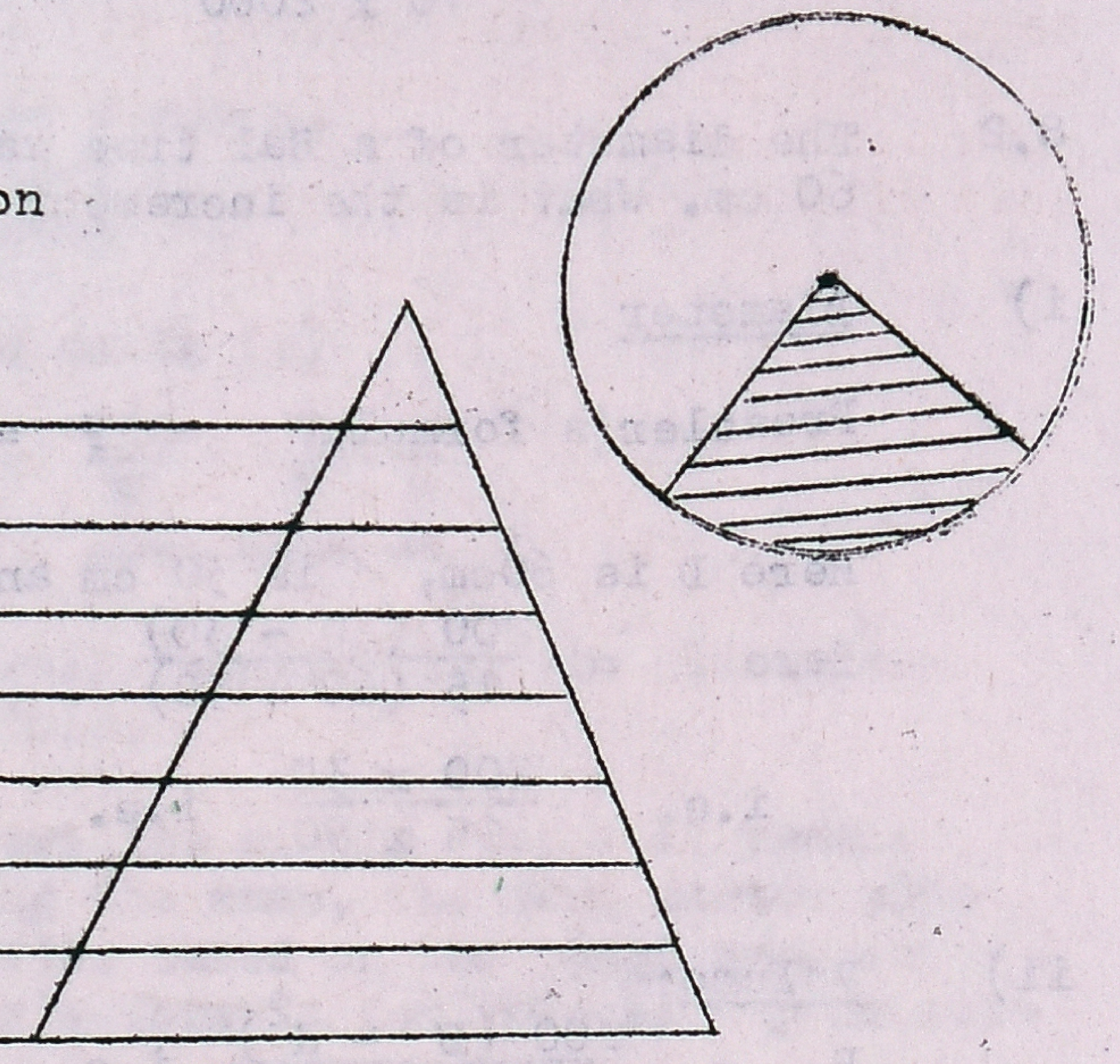
i) If the trees exhibit whorled branching as in the case of Bombax, Blue pine, *Pinus radiata*, etc. usually one internode represents one

year's growth. If it is desired to find out the height increment in the recent past the required number of internodes has to be counted from the tip and the height to this point deducted from the total height of the tree.

Example: If increment in the past 3 years has to be determined, 3 internodes has to be counted from the tip.

ii) Trees with Annual Rings: If the trees exhibit annual rings as that of Teak, the height increment during a particular period can be ascertained by means of stem analysis done at various points on the stem.

Height of Section	No. of Rings of Section
25.2M	..
21.0M	8
18.0M	20
15.0M	31
12.0M	40
9.0M	48
6.0M	55
3.0M	62
0.0M	67



If a stem is analysed for the number of rings on its cross section at 3m. intervals and the results are found to be as depicted above, the age height table showing the height increment will be as follows:

Height	Age taken to reach the height
3m	67 - 62 = 5 years
6m	67 - 55 = 12 years
9m	67 - 48 = 19 years
12m	67 - 40 = 27 years
15m	67 - 31 = 36 years
18m	67 - 20 = 47 years
21m	67 - 8 = 59 years
25.2m	67 - 0 = 67 years

If we want to find the height increment in respect of felled trees in the past n years, a point on the stem has to be reached by trial and error till it yields a section which contains "n" rings. The height of the tree from the point to the tip represents the height increment put on by the tree during the last n years.

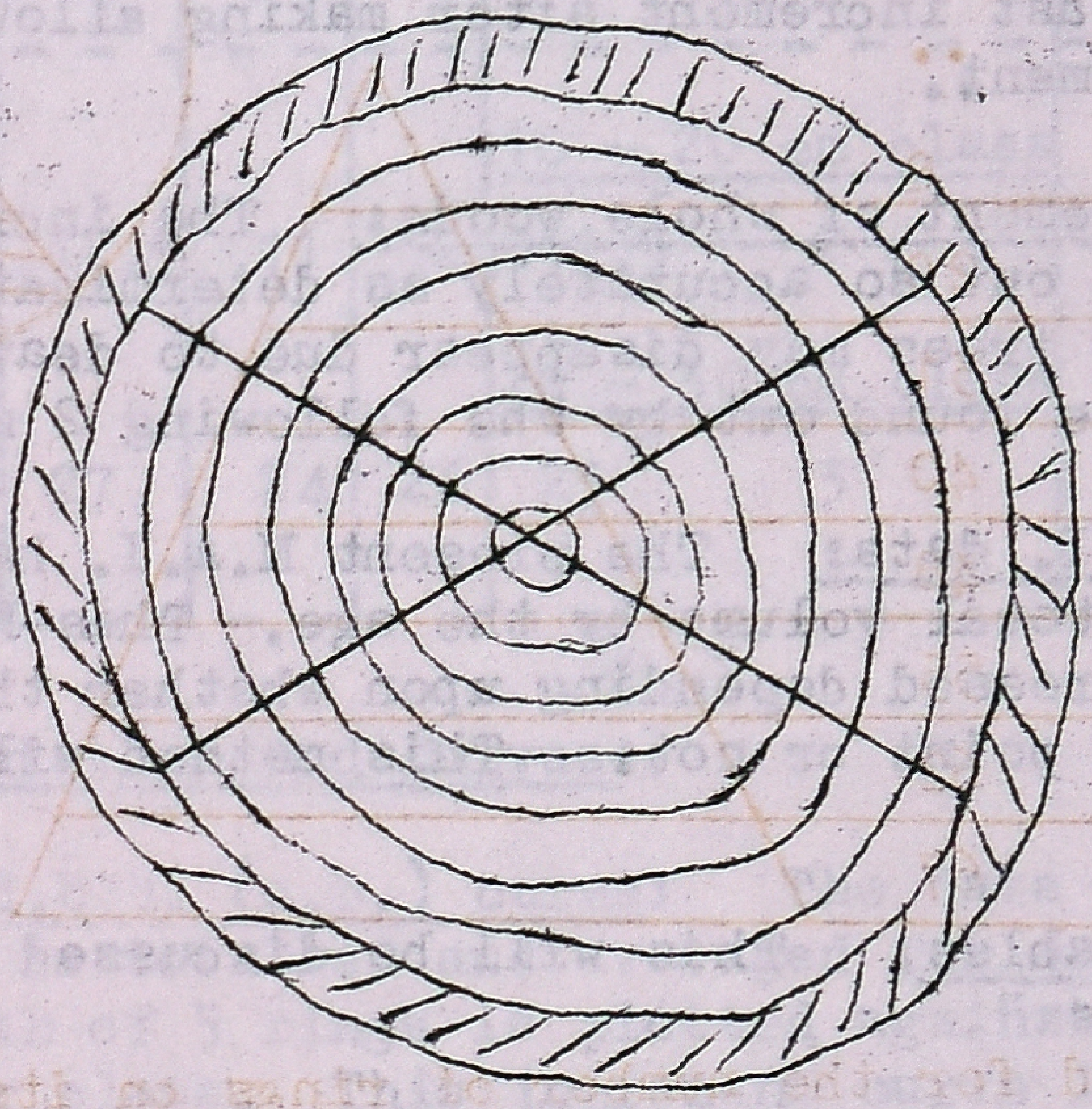
b) Prediction of Height Increment of Future: This has to be done on the basis of rate of increment attained in the past. This can be done by constructing the age-height curve based on the past data. This curve may be produced to predict the future data. Care should be taken to ascertain the time when the C.A.I. culminates. The increment may rise or fall depending upon the rise or fall of the increment just before the culmination. In this way the probable increment for a limited period, say 10 years can be predicted with a fair degree of accuracy.

9.2 Diameter Increment:

a) of the past:

i) of Standing Trees: Periodic measurements may be taken at breast height point with callipers. If immediate results are required, it can be determined with the help of Pressler's Borer. This can be used only in the case of tree exhibiting annual rings.

ii) of felled trees: The diameter increment of felled trees can be found out by stump analysis. We will study about stump analysis separately in detail. However it consists of measuring on the surface cross section of cut stump the length along average radii from the pith outwards to the periphery in pre-determined unit (say 1 or 2 cm.) This will be correlated with age as deduced from the number of rings which are counted. From this data age diameter relationship is tabulated after making allowance for i) Age taken by the tree to attain stump height ii) Diameter at B.H. (O.B) as against the diameter at stump height under bark actually measured.



b) of the future: The diameter increments of future may be predicted based on the increment of the immediately preceding periods, Proper allowances should be given for possible variations in the method of treatment like intensity of thinning.

9.3 Volume Increment:

a) of the past:

i) of standing trees: Volume increment during the past 'n' years may be determined as follows:

Find out the present diameter D. The corresponding height H and Form Factor F may be found out from the Diameter/Height and Form Factor tables. Present volume will then be S.H.F. where S is the basal area calculated from the D.

Similarly the volume before 'n' years may be found out by the formula s h f, s being calculated from d the diameter which is found out with the help of Pressler's Borer. Thus V - v(v = volume before 'n' years) will give the volume increment during the n years.

ii) of felled trees: This can be determined by stem Analysis. This is dealt with separately.

There is another rough method which may not be so accurate as that of stem analysis. The total height of the tree (H) and the diameter at mid point are measured. Find out the sectional area at this point. SH will be the volume which is V. Then the tree is cut off in the top portion with n rings in the bottom (where n is the number of years during which volume increment has to be determined). This may involve some trial and error. Let the height from the ground level upto this point (where there are n rings) be h. Then find out the cross sectional area at h/2 i.e., the mid point of the portion of the tree. Let this be s. The sh will give the volume of the portion of the tree i.e. the volume before n years. This will be v. Then Increment will be V - v or SH - sh for n years. Measurement of diameters should be taken under bark and with callipers only.

b) of the future: The future increment in volume can be estimated on the basis of immediate past increment after making allowance for possible variation in treatment.

10. Determination of Increment of whole woods: The increment of whole woods cannot be found out so accurately as determination of individual trees since many trees may disappear due to death, or thinnings, etc. This can be found out by the following 2 methods.

i) By making use of M.A.I. data: The present M.A.I. has to be determined by dividing the total volume by the age. This M.A.I. curve may be reduced or increased depending upon whether the M.A.I. has reached the culmination point or not. This method will give fairly accurate results.

ii) By the use of Yield Tables: This will be discussed in the later chapter " Yield Tables ".

Increment Boring:

11.1 Definition: Increment boring is defined as the boring of a tree stem with Pressler's Borer or any other borer to determine increment of trees with annual rings.

11.2 Object:

i) To determine the current increment of trees of given diameter, age or crown classes as an indication of the need of thinnings or regenerations.

ii) To determine the average time required for trees to pass through successive diameter classes to fix up yield or rotation.

iii) To determine the diameter increment of mature trees.

iv) To determine the effect of adverse or favourable factors and the response made to any improvement or control operations.

11.3 Field work: Select few typical trees of each diameter class. Measure 2 d.b.h. (o.b.) with callipers and find out their average and record them. Then remove the bark in the places where diameter was measured and measure two d.b.h. (u.b.) and find out their average and record them also. Then the tree should be bored at two ends of the diameter at right angle to the axis of the trees to a depth of 4 to 5 cms so that at least 15 to 30 rings are obtained on each radial core. The length of the outermost five rings of one end of each of

the 2 diameters on a particular tree is recorded and totalled. The data are collected diameter classwise in the following form.

Increment Borings

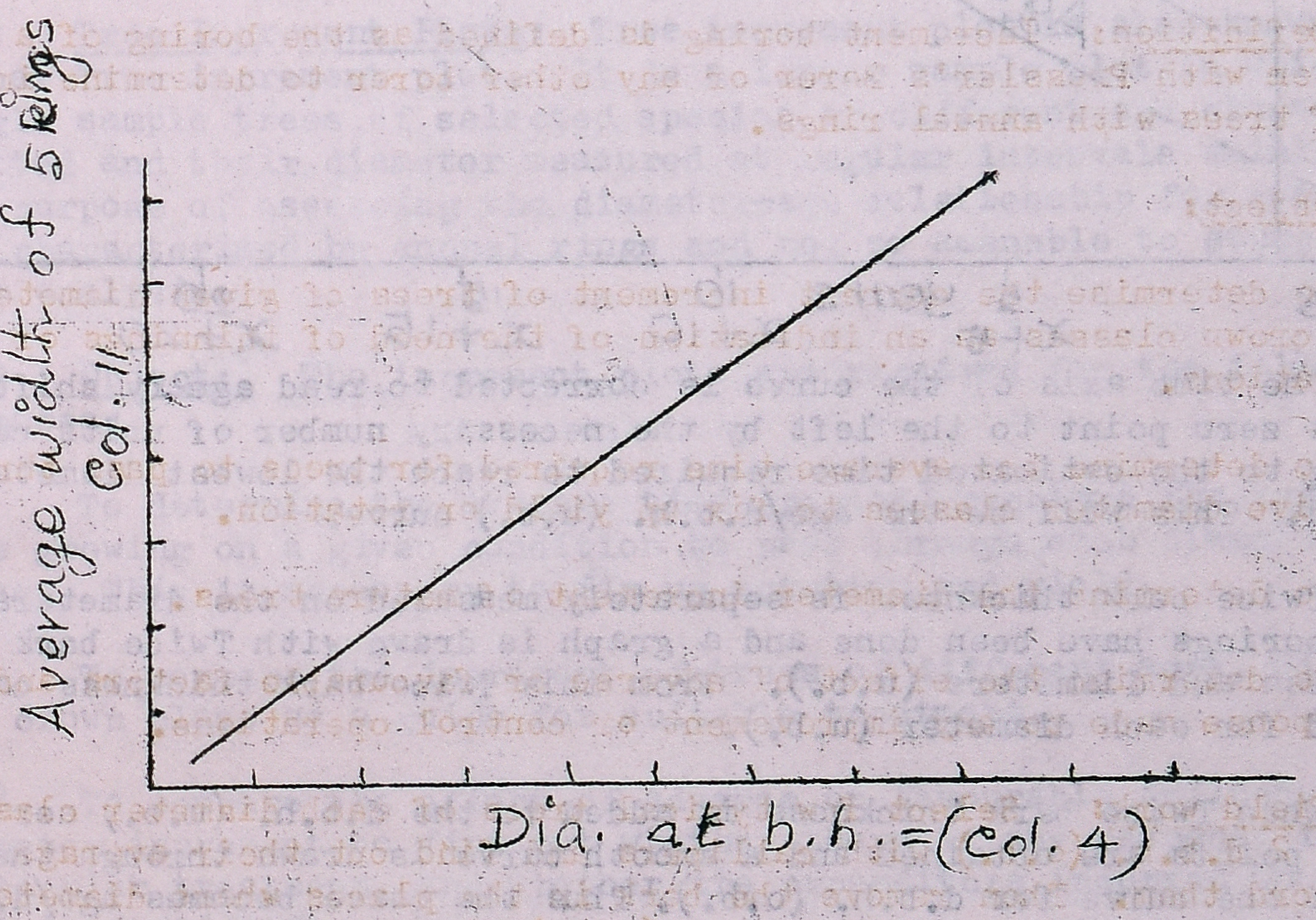
Species: Division:

Block & Compartment:

Tree No.	d.b.h. (O.B) D1	D2	Av.	d.b.h.(u.b.) D1	D2	Av.	Rings per cm of radius	Width of 5 rings in cm. r1	r2	Total
1	2	3	4	5	6	7	8	9	10	11
						10 - 20 cm class				
1	12	13	12.5	11	12	11.5	2	2.4	2.6	5.00
						20 - 30 cm class				
2	26	28	27	24	26	25	3	1.8	2.2	4.0

11.4 Computation and Curves:

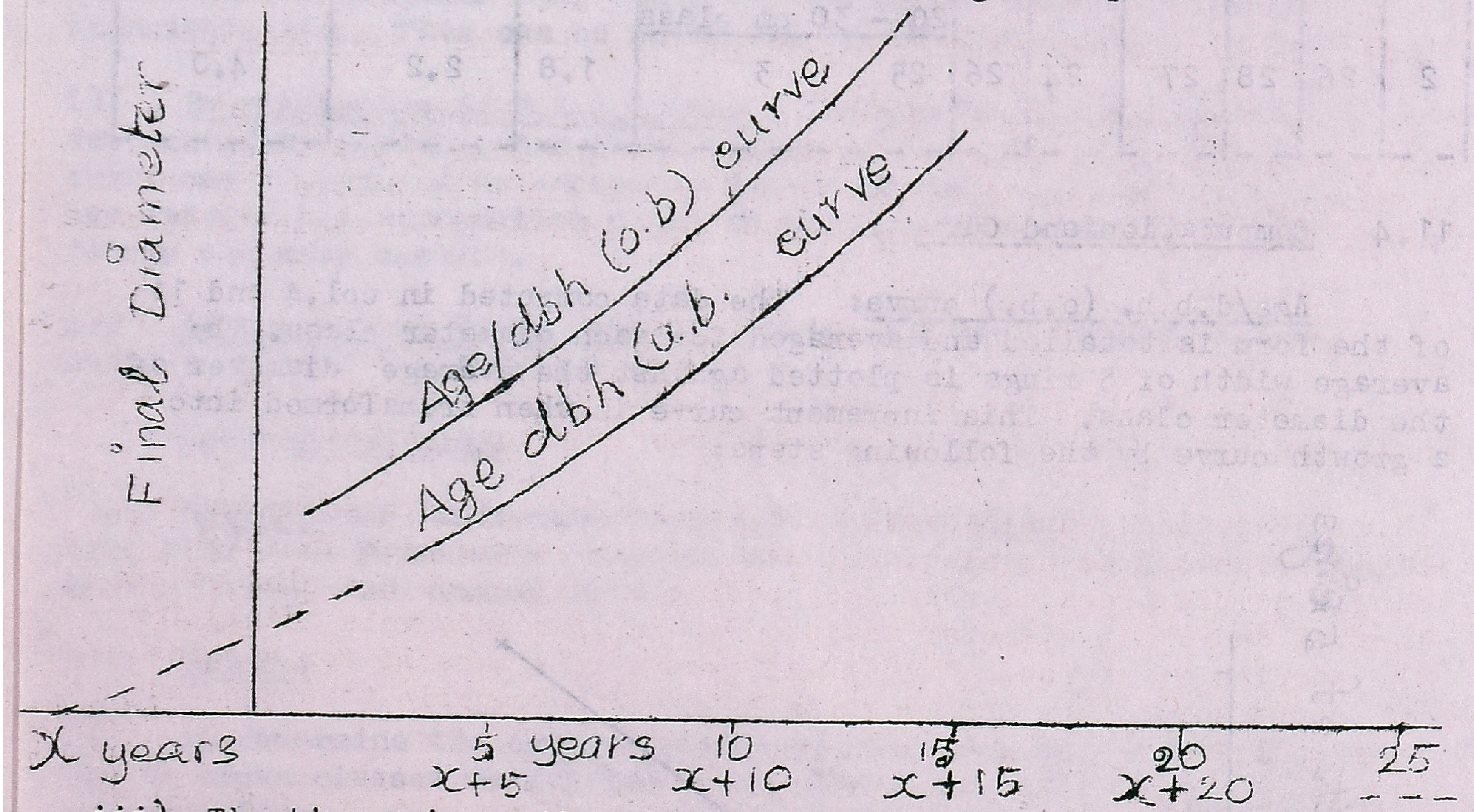
Age/d.b.h. (o.b.) curve: The data computed in col.4 and 11 of the form is totalled and averaged for each diameter class. The average width of 5 rings is plotted against the average diameter of the diameter class. This increment curve is then transformed into a growth curve by the following steps:



i) Find out the increment for the lowest diameter from the increment curve. Add this to the original diameter. Supposing the increment is read as 5 cm for the lowest diameter of 12 cm, this will be the increment for 5 years. Now add this 5 cm with the original 12cm. This 17cm. will be the final diameter after 5 years. Now find out as to what would be increment for this 17 cm from the curve. Suppose it is 7cm, this 7cm is the increment for 5 years. Hence the final increment after another 5 years will be 17 + 7 = 24 cm. This procedure may be repeated for the range of values available in the increment curve. It is tabulated as follows:

Initial Diameter	Increment	Final Diameter
12	5	17
17	7	24
24	6	30

ii) The diameter values so obtained are plotted against a succession of equidistant points at intervals corresponding to the number of years in the period i.e. 5 years with diameters in y axis and years in x axis and the growth curve is drawn through the points.



iii) The time axis of the curve is corrected to read age by shifting the zero point to the left by the necessary number of units corresponding to the estimated time required to reach the lowest diameter plotted. This will be the age/d.b.h. (u.b.) curve.

iv) Twice bark thickness is separately measured on the diameters on which borings have been done and a graph is drawn with Twice bark thickness and diameters (u.b.). From this Twice bark thickness can be read for each diameter (u.b.).

v) When Twice bark thickness is added to the d.b.h. (u.b.) series of new points are obtained and a smooth curve is drawn through them. This is the curve for d.b.h. (o.b.). Thus the curve becomes age/d.b.h. (o.b.) curve.

The age to reach a particular exploitable diameter can be found from this curve. This will also give the time taken by the

trees to pass through successive diameter classes. The difference between the ages to the middle of one diameter class and the one ~~blow~~ below it gives that period.

11.5 Advantages of Increment Borings as compared to Stump Analysis:

i) Borings are made on standing trees. Hence trees can be selected properly depending upon the purpose or object of the investigation.

ii) since data is collected on standing trees and not on stump, this gives a wide range of data.

iii) Borings are taken directly at breast height and hence no taper data is necessary.

iv) Work is quicker both in the field and in office. Hence, it saves time and money.

v) Observations can be repeated on the same tree at any later date.

11.6 Determination of Current Annual Growth Percent in Diameter:

By subtracting the width of 4 rings on diameter given in col.11 of the table from the diameters the diameter 5 years ago is obtained. If present diameter is D and the diameter before 5 years is d, the increment percent p can be calculated with Pressler's formula

$$p = \frac{200}{n} \times \frac{D - d}{D + d}$$

Determination of increment of trees without rings: There is only one method and that is through tree increment plots.

12.1 Tree Increment Plots: Tree increment plot is also known as Linear Tree increment plot. It is a linear sample plot in which single sample trees of selected species or different age classes are located and their diameter measured at regular intervals mainly for the purpose of assessing the diameter-age relationship for species not characterised by annual rings and not so amenable to stump and stem analysis.

12.2 Object: The increment plots are required for the following purposes:

i) To determine the average time (period) required for typical tree growing on a given condition to pass through each diameter class. This is necessary to fix up rotation and yield.

ii) To compare the increment of trees of different ages, diameter and crown class as a guide for suitable treatment.

iii) To compare the effect of adverse or favourable influence on diameter increment to find out whether there is any response for a particular treatment, and whether the expenditure incurred on improvement is justified.

iv) Collection of data for determination of crop increment in the irregular forest as stem and stump analysis may not be possible or stem and stump analysis involves felling of trees.

12.3 Difference between crop increment plot and Tree increment plot:

a) Tree increment plots are applicable to

i) unevenaged crops

ii) irregularly stocked forests

iii) mixed forest

iv) isolated trees

v) study of effect of factors affecting the adjoining trees differently e.g. defoliation.

vi) cases in which data from more trees of a given crown or size class are required than would be available in ordinary sample plots.

But sample plots are applicable to evenaged, uniformly stocked pure crops.

b) Tree increment plots are not exclusively in charge of the silviculturists as the sample plots.

c) Marking and fellings are done in the Tree increment plots as if these plots do not exist. But no marking and felling are done in sample plots as thinning, etč. is done only by the Silviculturists of the Research Wing.

12.4 Selection of Plots: The selected plots should cover adequately the whole range of quality, type and geographical distribution to be studied. The stocking should be typical of the forests to which the results obtained are to be applied with regard to uniformity and density.

12.5 Selection of Trees: All the trees in the plot need not be studied. Only those trees which are suitable for the object should be observed. The selected trees should be classified in accordance with the object in view into crown classes, defoliation classes, etc.

12.6 Shape and size of plots: They may be polygomal or linear. Linear plots may be conveniently of one or half chain wide and of any desired length. Polygomal plots should not exceed one acre. There should be a minimum of 25 trees in one plot.

12.7 Demarcation: The corners of polygonal plot should be marked with durable wooden posts, or concrete pillars or masonry pillars and serially numbered. They should be visible to each other. Trenches need not be dug out from post to post. The centre line of the linear plot may be cleared to the width of a path and durable pegs may be driven at every chain. The number of the plot or line should be indicated on a board conspicuously. The year of the laying out may also be written.

12.8 Numering (b): The trees to be measured, should be given a cross mark at breast-height and serially numbered. The number should be on the same side of the tree as the cross mark. The number will be painted, at about 15cm above the cross mark. In hilly areas, numbering should start from above and should follow stripwise, along contour lines.

Measurement of selected trees should be taken periodically and recorded and computed to draw the curves which will indicate the increment of these trees.

CHAPTER XI

STUMP AND STEM ANALYSIS

STUMP ANALYSIS

1. **Definition:** It is the analysis of a stump cross section by measuring annual rings in order to estimate the age of the tree and its past rate of diameter and basal area growth.

2. **Objects:**

i) To determine the progress of diameter increment on the average stump either over a desired period or throughout the life of the trees.

ii) To study the rate of diameter increment due to external influences like annual fires, drainage, fertilisation, insect attack, pruning, resin tapping, etc.

iii) To find out age/diameter relationship to determine the rotation age corresponding to a particular exploitable diameter in the absence of yield tables.

3. **Field Equipment:** Follwoing equipments should be taken to the field by each party.

i) Research calliper - 1
ii) Metallic tape - 30m. - 1
iii) Foot Rule - 30 or 60cm - 1
iv) Pocket tape (2m) - 1
v) Pocket lens - 1
vi) Haga Altimeter or Abney's level - 1
vii) Cross-cut saw - 1
viii) Sharp axe - 1
ix) Sharp adze or a chisel - 1
x) Pins - 25
xi) Water bottle with water - 1
xii) Stump Analysis forms 1,2,3 - As required.
xiii) Soft pencils - 2

Field work:

4. **Selection of trees:**

i) If old stumps are available, sound stumps of trees of rotation size should be selected. But these should not have been suppressed in the past life. This can be judged from the closeness of the annual rings on any part of the stump. The stumps should be of average trees so that they can serve as representatives of the crop.

ii) If old stumps are not available trees should be selected and felled. The selected trees should satisfy the following conditions.

a) They should be of rotation size and over.
b) They should be representative of the site quality to which results are to be applied.
c) They should be of typical shape and development.
d) Do not select suppressed trees or trees of abnormality or malformation.
e) Do not select trees of above average quality.

f) Each site quality may be dealt with separately.
g) In case of buttressed stumps, analysis should be done at a higher level.

5. Dressing the stump:

i) After selection, the diameter at breast height is measured and then the tree is felled.

ii) Dress the stump so that the surface is horizontal. This may be done by sawing off the protruding portion in the stump.

iii) Keep the stump as low as possible.

iv) Even in the case of old stumps, cross-cutting will have to be done, leaving a smooth and horizontal cross-section.

v) Remove a ring of bark at the top edge of the stump for taking the under bark measurements.

vi) Let the height of the stump be uniform, as far as possible.

6. Measurement on Stumps:

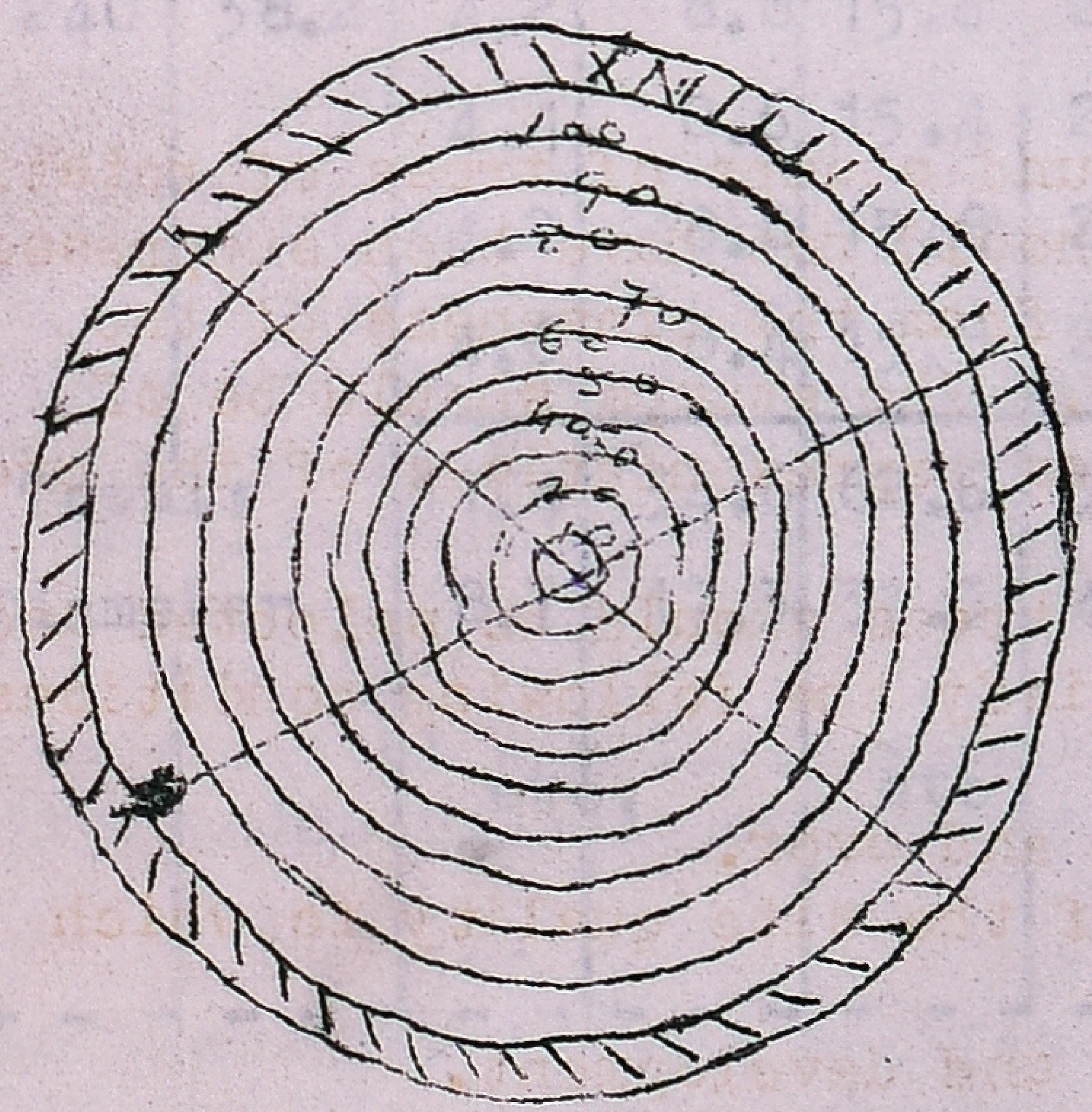
6.1 i) Stump height: Measure from the ground level to the level of the pith, from the uphill side, nearest to one c.m.;we will have to add an allowance for age to grow upto this height.

ii) Girth (U.B.): Measure the girth under bark at the top edge of the stump nearest to 1 mm.

iii) Now you can calculate the corresponding average radius (from the girth measured).

6.2 Ring counting and radial measurements:

i) Selection of 4 Radii: It is rare that the stumps are circular in section or the piths be at central position. Hence select 4 radii, on the stump. Let the radii be angularly as far apart as possible i.e. they should be spaced as widely as possible. The ideal radii should be at right angles. Their lengths should be approximately equal to the calculated radius (6.1 - iii). The selected radii should be marked on the stump with a scale and pencil. The thumb rule is to select the 4 radii such that their average lengths are more or less equal to the calculated radius.



ii) If rings are not visible, the surface may be moistened with water or chiselled along the radius.

iii) Adjustment of radius:

If the radii on the stump

differs appreciably from average radius, the selected radii may be multiplied by the adjustment factor(which is equal to the average radius divided by Actual Radius). The radial measurements should also be multiplied with this factor. In the remarks column of the stump Analysis Form No.1, it should be recorded " Adjusted " against radial measurements which are so adjusted.

iv) Marking of decades: On each marked radius, decades (10 rings) are counted from pith outwards. A pin is inserted in each decade. Incomplete decade (odd rings) should be left on the outer periphery. Incomplete and false rings should not be counted. To ensure this pins can be fixed at each decade independently on all the four radii and then checked to see that all the 4 pins of the same decade lie on the same continuous ring.

v) Radial measurements by decades: The length of each decade on each of the marked radius is measured, from pith outwards in centimetres and millimetres. This measurement should be done in one setting of the scale on each radius so as to avoid the error.

The total number of rings upto the circumference may be counted.

6.3 Tabulation of measurements:

i) Radii at successive decades: The radii at each successive decades is measured and entered in the stump analysis Form No.1. For this the distance from the pith is measured upto each decade. Then the radii at successive decades are totalled for each stump and then halved to get the average diameter by decades.

ii) Diameter at successive decades: The data in Form No.1 are consolidated to read diameter at successive decades and entered in stump analysis Form 1(a).

P. T. O.

STUMP ANALYSIS FORM No.1

RADII AT SUCCESSIVE DECADES

Species: Division:

Quality: Block & Compartment:

Tree No.	Stump height	Girth U.B. at Stump height cm.	Calculated Average Radius at Stump ht. c.m.	Radius at successive decades 10	20	30	40	50	60	Total No. of Rings.	Total length of Radius in cm.	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13
1.	15	210	33.4	3.8	8.4	15.2	22.2	30.2	..	56	33.4	..
				4.2	8.6	15.4	22.4	30.4	..	56	33.6	..
				3.6	8.2	15.6	22.6	30.6	..	56	33.2	..
				3.4	8.4	15.4	22.8	30.8	..	56	33.4	..
		Total:		15.0	33.6	61.6	90.0	122.0				
Average Diameter i.e. half the total.				7.5	16.8	30.8	45.0	61.0				
2.	16	227	36.0	3.6	8.7	14.8	22.0	31.0	..	55	35.6	..
				3.8	8.6	15.2	22.4	31.6	..	55	36.2	
				3.4	8.8	15.4	22.6	31.4	..	55	35.8	
				3.6	8.4	15.6	22.2	31.2	..	55	35.6	
				14.4	34.5	61.0	89.2	125.2				
Average Diameter				7.2	17.2	31.0	44.6	62.6				
3.	15	240	38.2	4.2	8.8	15.6	23.4	32.6	..	56	38.2	
				4.4	8.6	15.4	23.2	33.4	..	56	38.0	.
				4.2	8.8	15.8	23.4	32.2	..	56	37.8	
				4.6	8.4	15.8	23.6	33.2	..	56	37.2	
		Total:		17.4	34.6	62.6	93.6	131.4				
Average Diameter				8.7	17.3	31.3	46.8	65.7				
				etc.		etc.		etc.				

STUMP ANALYSIS FORM 1(a)

DIAMETER AT SUCCESSIVE DECADES

Species: Division:
Quality: Block & Compartment:

Tree No.	Stump Height cm.	Stump Diameter UB cm	Stump Diameter at successive Decades							Remarks
			10	20	30	40	50	60	70	
1	15	66.8	7.5	16.8	30.8	45.0	61.0	-	-	-
2	16	72.0	7.2	17.2	31.0	44.6	62.6	-	-	-
3	15	76.4	8.7	17.3	31.3	46.8	65.7	-	-	-
4	15	68.0	7.6	17.6	30.2	46.4	65.8	-	-	-
5	16	64.2	7.2	15.2	27.4	44.8	62.8	-	-	-
6	15	72.8	7.6	17.6	31.2	44.0	63.0	-	-	-
7	16	74.8	8.4	17.1	31.0	46.2	66.0	-	-	-
8	15	70.0	7.6	16.8	30.4	44.2	64.0	-	-	-
9	16	74.8	8.0	16.8	31.0	46.8	67.0	-	-	-
10	15	72.4	7.8	16.4	30.8	46.4	66.8	-	-	-
Total	154	712.6	77.6	168.8	307.1	455.2	644.7		-	-
Average	15.4	71.3	7.7	16.9	30.7	45.5	64.5		-	-

Age to Stump height:

7.1 The above data, if drawn into a curve with stump diameter against the corresponding decades will give the number of years taken for the growth of the tree to reach the particular diameter. But we want to assess the age of the tree as a whole. For this, we require the number of years required to the tree to grow upto the stump height. Hence the following data has to be collected.

7.2 a) Select about 10 - 20 freely growing seedlings in the same locality of height of about 2 metres, depending upon the heights of the stumps analysed.

b) Cut the seedlings at ground level and also at different heights of 10, 20, 30, 40, 50cm and 80cm (if necessary also at 130 and 180cm if the stumps are higher than 80cm).

c) Count the number of rings at each cut end and determine the age at different heights. This data may be entered in Stump Analysis Form No.2. The readings may be totalled and averaged.

STUMP ANALYSIS FORM No.2

SEEDLING HEIGHT DATA

Species: Division:

Quality: Block & Compartment:

Saplings	Ground level	Age at successive height from ground level: 10cm No. of rings	10cm Age in years	20cm No. of rings	20cm Age in years	30cm No. of rings	30cm Age in years	40cm No. of rings	40cm Age in years	50cm No. of rings	50cm Age in years	etc.
1.												
2.												
3.												
4.		etc.		etc.		etc.						
Total												
Average												

8. Conversion of Stump Diameter (U.B) into D.B.H. (O.B):

8.1 Generally we measure the diameters only at breast height. But here, we have cut the stumps at a low level and done the analysis. Hence it is quite necessary to convert the stump diameter (U.B) into D.B.H.O.B. This can be done as follows:

8.2 a) Select a number of trees of different d.b.h. classes.

b) Measure their d.b.h. (o.b.)

c) Measure the under bark diameters at 15cm, 45cm, and 75cm from ground level.

d) This height depends upon the stump heights of stump you have analysed.

e) Tabulate the data in Stump Analysis Form No.3.

STUMP ANALYSIS FORM No.3

TAPER DATA

Species: Division:

Quality: Block & Compartment:

Sl. No.	Diameter class in Centimetres: 20-30 Stump Diameter U.B.			D.B.H.-O.B.	30 - 40 Stump Diameter U.B			D.B.H.-O.B.	40 - 50 Stump Diameter U.B.			D.B.H.-O.B.	50 - 60 Stump Diameter U.B.			D.B.H.-O.B.
	At 15 cm	At 45 cm	At 75 cm		At 15 cm	At 45 cm	At 75 cm		At 15 cm	At 45 cm	At 75 cm		At 15	At 45	At 75	
1.																
2.																
3.																
Total																
Average																

9. <u>Drawing of Curves:</u>

9.1 <u>Curve 1:</u> <u>Seedling height curve:</u>

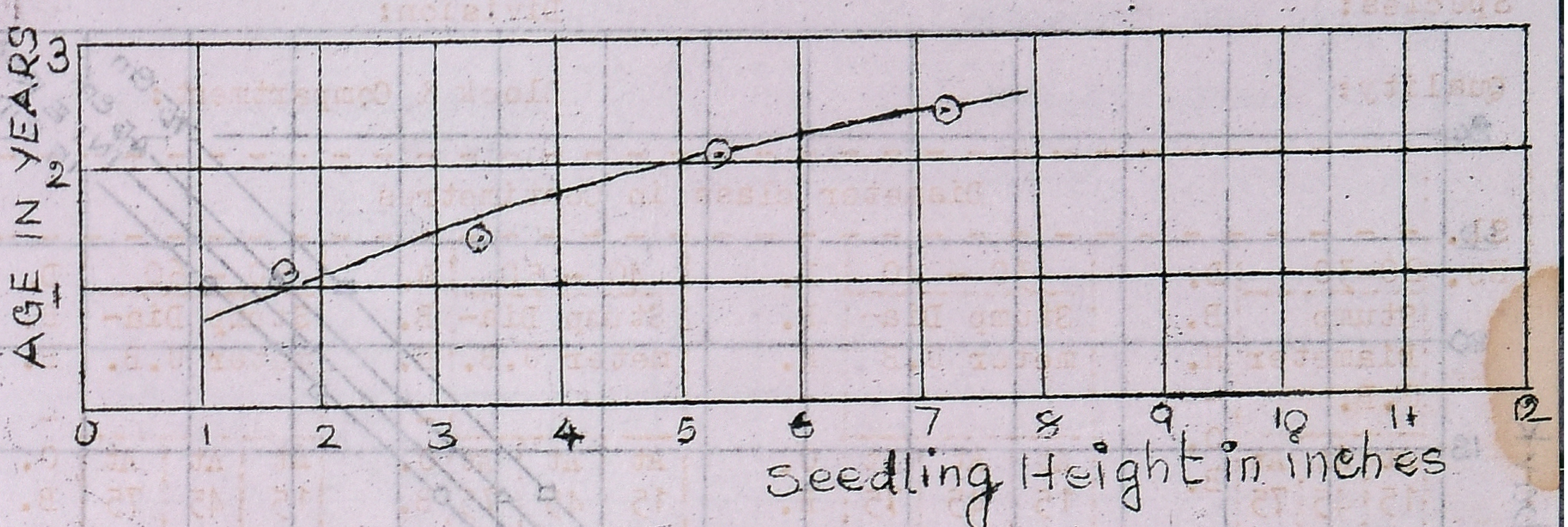
i) Read para 7. You have collected data and entered in Form 2. This data is plotted, showing heights in abscissa (X axis) and ages on ordinate (Y axis). The average ages at various heights are plotted and a

P T O

smooth curve is drawn.

Seedling height curve

CURVE NO.I



ii) From the above curve, the age corresponding to average stump height is read and tabulated as follows:

Average Stump ht.	Age in years
10 cm	..
20 cm	1 year
30 cm	1.5 yr.
40 cm	2.0 yr.
50 cm	2.5 yr.
60 cm	3.0 yr.

iii) This age is then used to adjust the stump age at ground level. For example the age is 1.5 years for the stump to reach 30cm stump height. This age should be shifted in advance by 1.5 years in the main curve so that y axis will read the total age.

9.2 Curve 2: Conversion of Stump diameter U.B. to d.b.h. U.B.:

i) Read para 8. You have collected data of stump diameter U.B. and corresponding d.b.h. o.b. and made entries in form No.3.

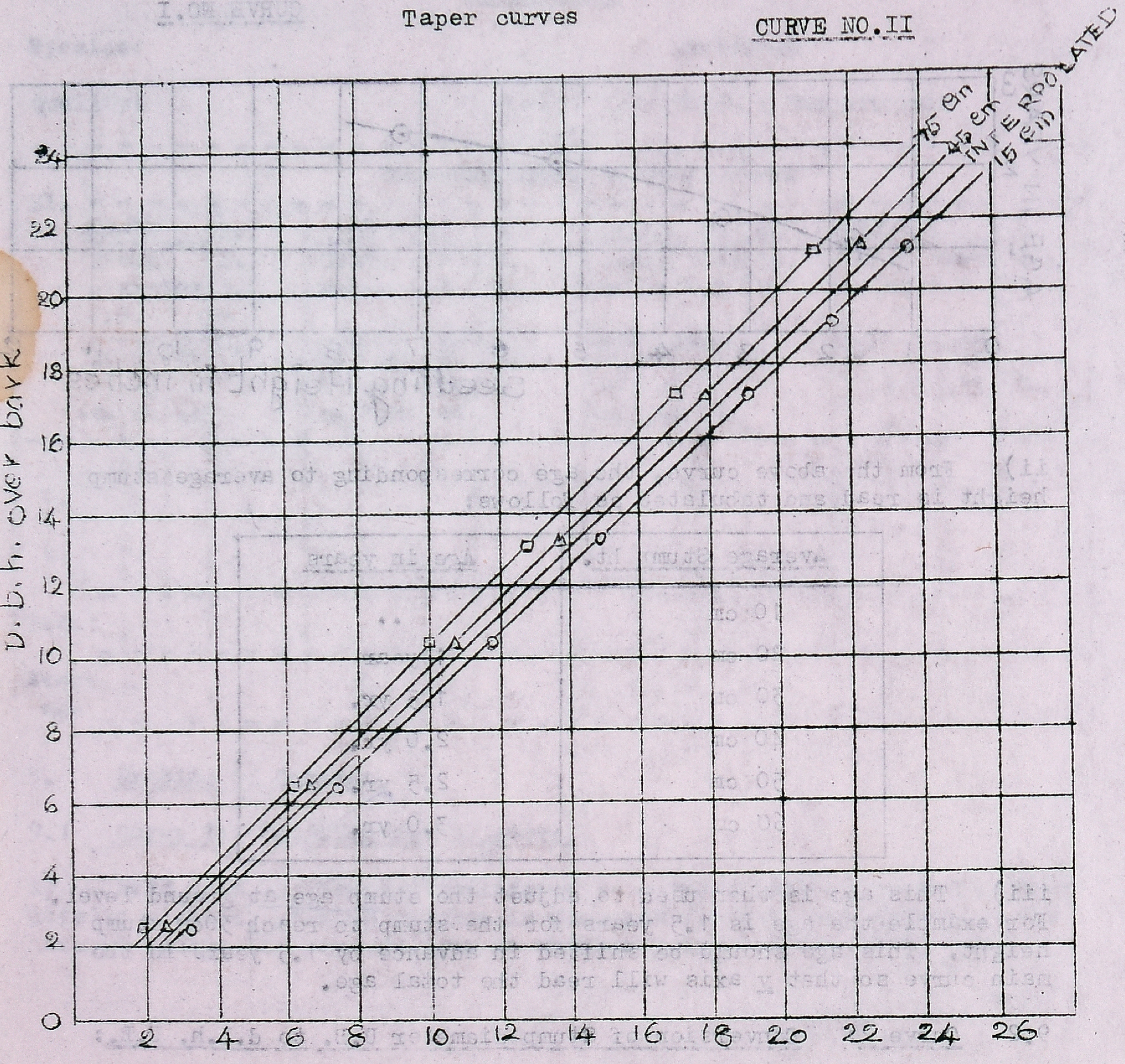
ii) The average stump diameter at different heights of various d.b.h. classes may be plotted against corresponding d.b.h. (o.b.) and a smooth curve drawn.

iii) This curve will have 3 close set of curves which will all be

STUMP ANALYSIS

Species: Acacia catechu   Division: Tarai & Bhabar

Taper curves   CURVE NO.II



Stump diameter under bark

Stump diameter:-	2	4	6	8	10	12	14	16	18	20	22
D.b.h.(o.b.):-	1.9	3.8	5.6	7.4	9.3	11.1	13.0	14.9	16.7	18.6	20.4

straight line. If the dispersion of these curves is appreciable, an additional curve may be interpolated corresponding to the average stump height. If the curves are very close, the curve which corresponds most nearly to the average stump may be used for further computation.

::::::

iv) From the above curve, a statement may be prepared showing the D.B.H. O.B. for the stump diameter U.B. for a stump height of 30cm. This will be useful for the final curve.

Stump Diameter	10	20	30	40	50	60	70
D.b.h. O.B.	5	10	20	25	35	40	50

10. <u>Curve 3:</u> <u>Stump Diameter and D.B.H. (O.B.) against age:</u>

Now we can draw the final curve showing the d.b.h. (o.b.) against total age in the following steps:

Read the para 6 and 7.

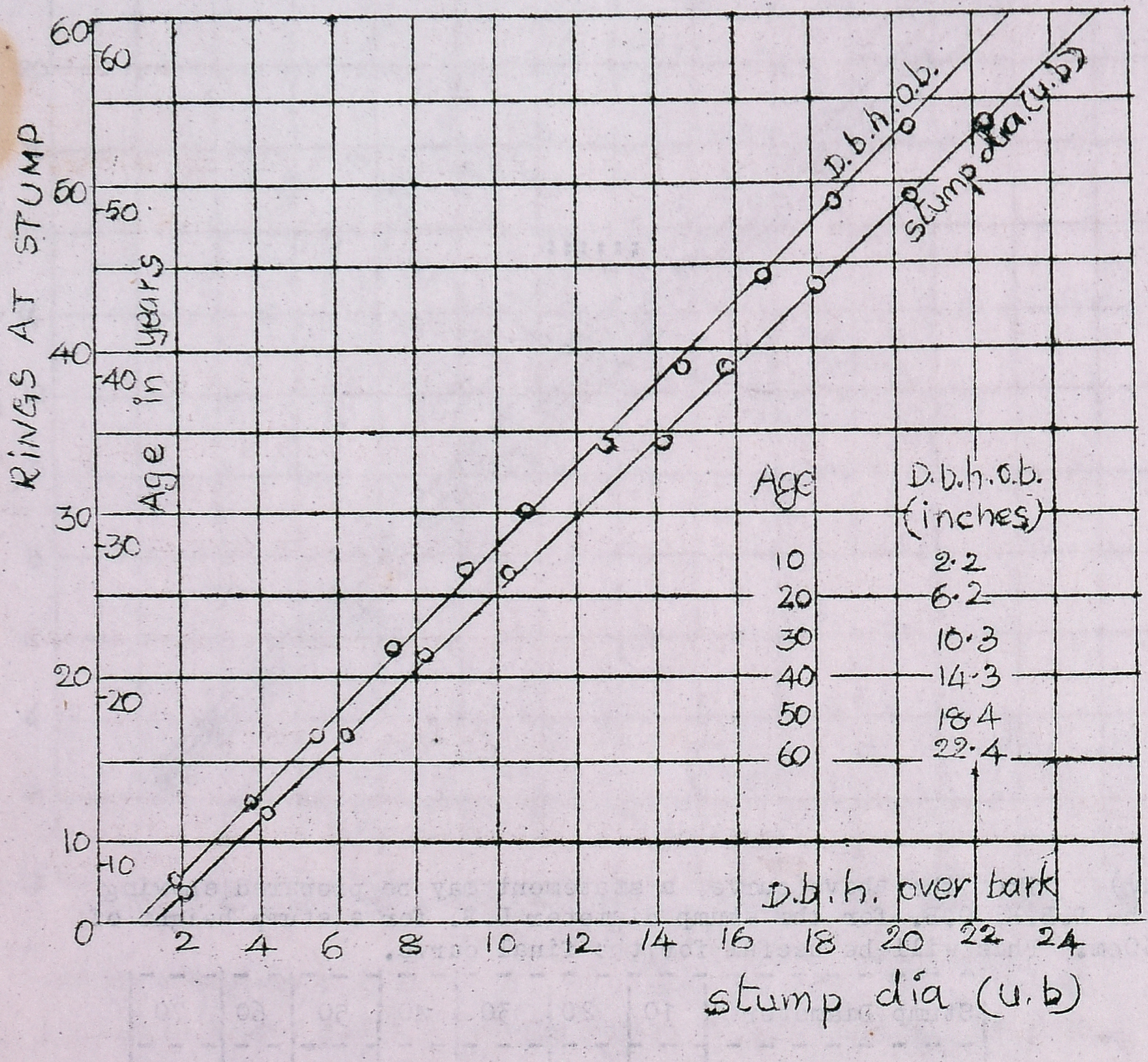
<u>Step 1:</u> Average diameter readings taken from Form 1(a) for various decades may be plotted. Stump diameter (u.b.) may be taken in <u>x</u> axis and decades at stump height may be taken in <u>y</u> axis and a smooth curve may be drawn.

Step 2: The y axis shows the age of stump. This may be corrected to show the correct age. This can be done by shifting down the scale by the number of units equal to the number of years, a tree takes to grow to average stump height, read from curve No.1. For example it has been assumed that it takes 2 years to grow to the average stump height in the graph. Accordingly it has been shifted and ages have been corrected.

Species: Acacia catechu Division: Tarai & Bhabar

STUMP DIAMETER & d.b.h. CURVES

CURVE NO.III



Third step: X axis gives stump diameter (U.B.). This may be corrected to read the d.b.h. (O.B) with the help of the interpolated curve in curve 2 - which gave d.b.h. (o.b.) corresponding to various stump diameters (U.B). From this curve we have read the d.b.h.(o.b.) for various stump diameters (U.B)/ may be located in Curve 3 and shifted backwards on the same age axis to a point corresponding to

/ The points of Stump Diameters (U.B.)

the d.b.h. (o.b.). Thus you will get a new set of points. A smooth curve may be drawn through these points. This curve will give d.b.h. (o.b.) corresponding to the total age of the tree and the age which a tree takes to reach a particular diameter can be read from this curve. From the curve a tabular statement may be prepared.

Age in years	10	20	30	40	50	60	70
D.B.H.(O.B) in cm	5	15	26	36	46	56	62

11. Advantages: Stump analysis has the following advantages as compared to other methods.

i) Data can be collected from the stumps of any felled trees as long as the wood remains sound. Thus this does not require any felling of trees.

ii) Data can be collected at any time and with a minimum labour.

iii) The data can be multiplied to any desired extent with no objection other than the time taken in measuring.

iv) Field work is simple and easily learnt.

v) Each stump provides data for the whole life of the tree.

12. Applicability: This method is applicable to the following investigations:

a) Rapid collection of diameter increment data in current or recently worked coupes.

b) Wherever investigations require a large number of data spread all over the forest areas.

c) Whenever there is objection for felling of trees.

Note: If you have any confusion in curve 3, you can draw a separate curve as curve 4 which will have the age in years (after shifting) under y axis and d.b.h. (o.b.) in x axis and call it as curve No.4.

PROBLEMS

1) Define Stump Analysis. Explain how you would carry out the Stump Analysis. What are the advantages?

2) Define Stem Analysis. Explain how you would carry out the Stem Analysis and draw the various curves?

3) What are the advantages of Stem Analysis?

STEM ANALYSIS

13. Definition: Stem analysis is defined as the analysis of a complete stem by measuring annual rings on a number of cross sections at different heights to determine its past rates of growth.

14. Objects:

i) To determine age - diameter, age - height and age - volume relations throughout the life of the tree analysed.

ii) To assess the average rate of diameter, height and volume increment.

iii) To determine the effect of external influences like lopping, pruning, defoliation, fire, etc. on the rates of growth of trees.

iv) To prepare local volume tables by correlating diameter-volume relations.

15. Applicability: This method is applicable in

i) Estimating volume increment in unevenaged forests.

ii) Following past height increment in sample plots.

16. Field Equipment (for each party):

a) Felling equipments:

i) Cross cut saw - 1
ii) Hand saw or bow saw - 1
iii) Iron wedge - 5
iv) 5 kg. hammer - 1
v) Sharp axe - 1
vi) Sharpening files - 2

b) Measuring Equipments:

i) Research calliper - 1
ii) Measuring scale - 1 (30 or 60cm)
iii) Measuring tape - 1 (30m)
iv) Abney's level or Haga Altimeter - 1
v) Sharp adze
vi) Chisel - 1
vii) Pocket lens - 1
viii) Water and water bottle.

c) Stationery:

i) Pins - 50
ii) Soft pencils - 2
iii) Stem analysis forms 1,2,3 as required.

Field work:

17.1 Selection of Area: Heights of typical mature trees may be

measured either with instruments or ocularly so as to know about the site quality of the forest area. If the area has different site qualities, the work may be done for each site quality.

17.2 Selection of Trees:

i) Number of trees selected will depend upon the area of the forest.

ii) Selected trees should be well spread in the site.

iii) The selected trees should be typical representative of the area with special reference to the growth conditions for which data is required.

iv) Trees above average quality should not be selected.

v) Trees should be of rotation size and over.

vi) Suppressed and markedly dominated trees should not be selected.

vii) At the same time, isolated trees should not also be selected.

viii) Abnormal trees or trees with any kind of malformation should not be selected. But minor defects need not be taken into account.

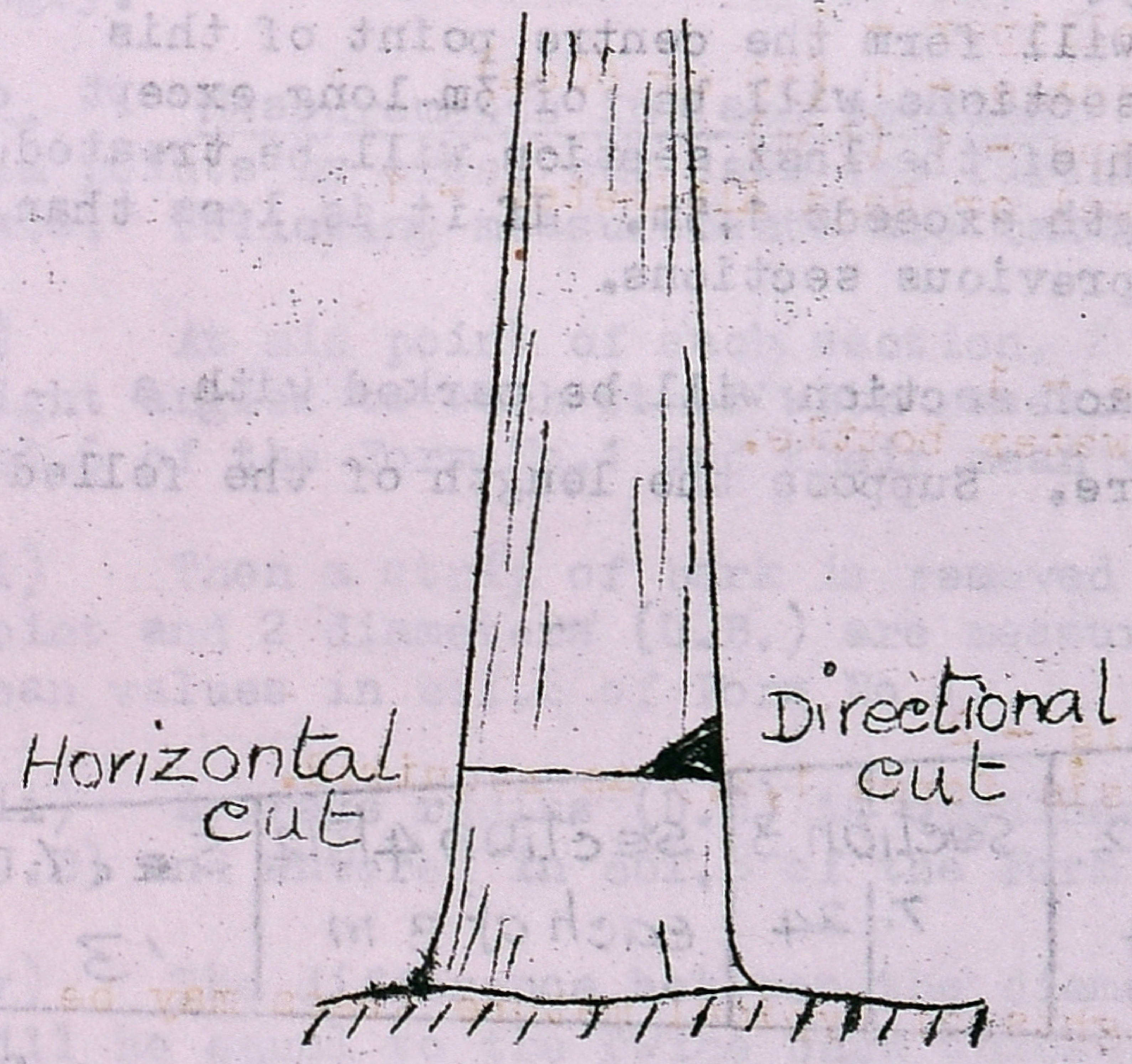
18. Measurement of Trees before felling:

i) Measure the d.b.h. (o.b.) of the tree and enter in the stem analysis form 1.

ii) Make a horizontal mark at the breast height level round the bole.

19. Method of felling:

i) Give a directional cut to the tree facing the direction of fall. Let this cut be of one third the width of the tree.



For this, a wedge shaped portion of the wood may be removed with axe. Then a horizontal cut may be given with a cross cut saw. Then a slanting cut may be given with a saw or axe - just 5 to 8 cm above this horizontal line which will meet the inner edge of the lower cut.

ii) Now start sawing of the stem from the opposite direction. If necessary an iron wedge may be driven into the saw cut with the help of a hammer so as to allow free movement of saw. With the progress of sawing, 2 or 3

wedges may be driven into the saw cuts so that the tree will fall in the required direction on the side of the directional cut.

iii) Care should be taken to see that falling tree does not cause any damage to the adjacent trees or labourer. The moment the top of the tree starts bending, you must warn others about the fall of the tree by a " shouting ".

20. <u>Measurements on the felled trees:</u> Following measurements should be taken and recorded before the tree is cross-cut into sections.

i) The length of the stem including the stump to the point at which a diameter over bark is 20cm (for standard timber volume of tree).

ii) The length of the stem to the first green branch and lowest point with green crown on all sides (clear bole and crown length).

iii) Length of the stem upto a diameter limit of 5cm o.b.(Standard stem small wood).

iv) The total height of the tree.

v) The diameter over and under bark at the point mid-way between breast height and tip (Form quotient).

vi) The length excluding stump and defective butt to any point on the stem which is utilisable. (Commercial bole length)

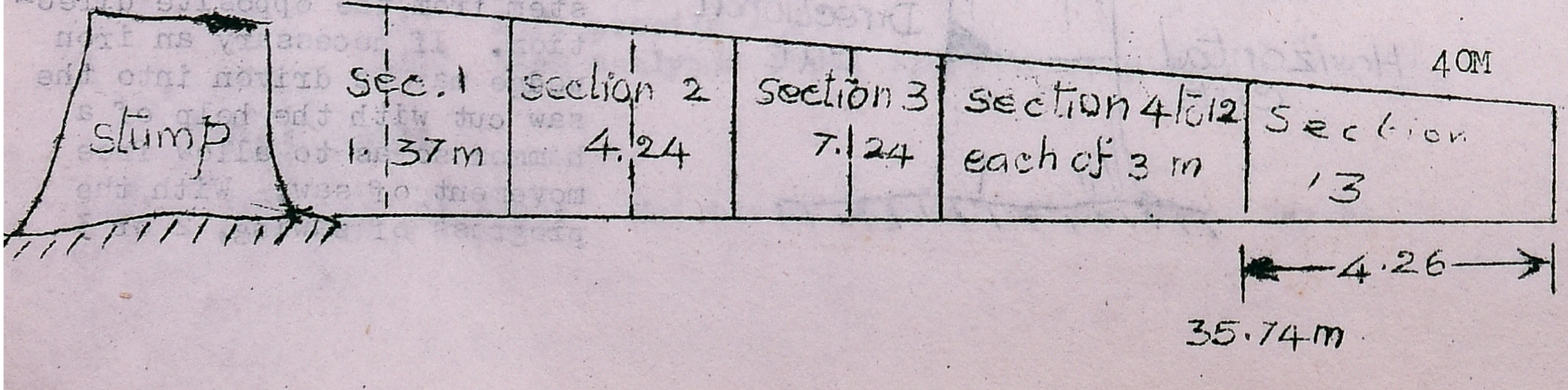
vii) Under bark diameters at the mid-points of convenient sections of this commercial bole, each section not exceeding 6m (Commercial volume in the round).

viii) Diameter over bark and under bark at the mid point of the commercial bole (Bark percentage in commercial bole).

21. <u>Dividing the stem into sections:</u>

i) The felled tree is then divided into sections from the ground level point (including the stump). The first section will be of 2.74m so that the breast height point will form the centre point of this section. Each of the remaining sections will be of 3m long except the last section. The odd length of the last section will be treated as a separate section if the length exceeds 1.5m. If it is less than 1.5m, it will be added with the previous sections.

ii) <u>Marking:</u> Mid points of each section will be marked with a tree scribe as shown in the figure. Suppose the length of the felled



tree is 40m, the tree will be divided into sections and mid point of each section marked will be as follows:

Section No.	Length of each section	Length at which mid point has to be marked for cutting	Length at which each section ends
1	2.74m	1.37m including stump ht.	2.74m including stump ht.
2	3.0m	(2.74+1.50)=4.24m.	5.74m.
3	3m	7.24m	8.74m
4	3m	10.24m	11.74m
5	3m	13.24m	14.74m
6	3m	16.24m	17.74m
7	3m	19.24m	20.74m
8	3m	22.24m	23.74m
9	3m	25.24m	26.74m
10	3m	28.24m	29.74m
11	3m	31.24m	32.74m
12	3m	34.24m	35.74m
13	3+1.26= 4.26m	37.87m	End of tree 40m.

iii) Suppose the mid points of sections fall on points unsuitable for ring counting, due to knots, rot or some other malformation, the mid points may be shifted this side or that side upto a limit of 30cm - sections being treated as if they were actually at mid point. If it goes beyond this limit, the length of sections affected may be changed to avoid the difficult portion and the mid point can be marked accordingly.

22. Measurements in each section: The tree is then cut at the marked mid points by cross cut saws for further measurements and computation of data. Following measurements are taken.

i) At mid point of each section, 2 diameters (O.B) are measured at right angles to each other with research callipers and recorded in col.5 of the Form No.1 and their mean worked out.

ii) Then a strip of bark is removed alround the section at its mid point and 2 diameters (U.B.) are measured and recorded together with the mean values in col.6 of Form No.1.

iii) Average radius (U.B) is obtained by halving the mean diameter (U.B) and entered in col.8 of the Form No.1.

iv) The difference between the diameter (O.B) and the diameter (U.B) will be equal to the Twice bark thickness and this will be entered in col.7 of the Form No.1.

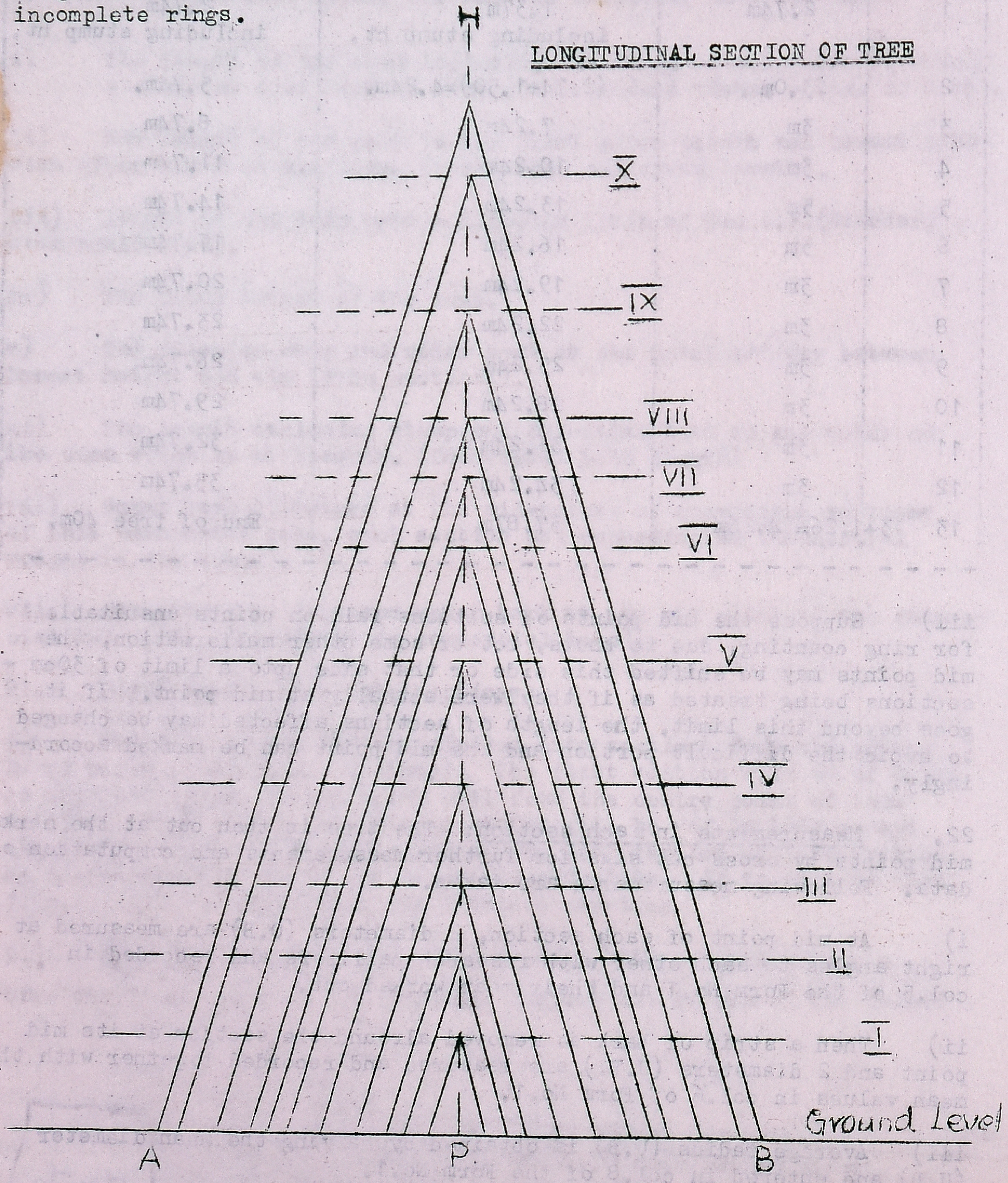
v) If ring counting is not able to be done in the field for want of time, traverse sectional disc of 5 to 8 cm thick can be sawn and brought to office for counting of rings.

23. Ring counting for Age measurements:

i) See whether the annual rings are clear. Moisten the sections with water. Otherwise chisel the plane so that the rings are visible.

ii) At mid points on each section, the total number of complete rings should be counted and entered in col.4 of the Form No.1. Avoid incomplete rings.

LONGITUDINAL SECTION OF TREE



STEM ANALYSIS FORM No.1

RADIAL MEASUREMENTS

Tree No.

Species:

Division:

Quality class:

Block & Compartment:

Crown class :

Sl.No. of Section	Ht. of Section	Age to Section	Rings in Section	Diameter O.B	Diameter U.B.	Twice bark thickness	Average radius U.B. Cm.	Length of Section in Metre	Radius at successive decades (in Cm & mm) 80	70	60	50	etc.	Additional measurements
1	2	3	4	5	6	7	8	9	10	11	12	13	etc.	14
1.	1.37	0	86	61.8	57.6	4.2	28.8	2.74	27.60	24.45	22.50	18.60		1. D.B.H. O.B
				61.8	57.6				27.75	24.45	28.45	20.40		2. D.B.H. U.B
				61.8	57.6						etc.			3. Total height 4. Crown width
						Diameter			55.35	48.9	51.0	38.00		5. Total height after felling
2.	4.24 M	1	82	54.3	52.5	2.7	25.80	3						6. Height of 1st green branch
				54.3	50.7				26.4	23.4	21.7	17.6		
				54.3	51.6				26.8	23.6	21.8	19.4		7. Height of lowest point of full crown
						Diameter			53.2	47.0	43.5	37.0		8. Clear bole length
3.	7.24	11	75	52.2	49.8	2.4	24.8	3	etc.		etc.	etc.		9. Crown length
				52.2	49.5									10. Height of 20cm d.o.b.
				52.2	49.6									11. D.u.b. at Mid point above b.h.
						Diameter								
4.	10.24	21	65		etc.				etc.		etc.	etc.		
						Diameter								

STEM ANALYSIS FORM No.2

SEEDLING HEIGHT DATA

Readings at successive heights											
Ground level		10cm		20cm		30cm		80cm		130cm	
No.of rings	Age yrs.	No.of rings	Age yrs.	No.of rings	Age yrs.	No.of rings	Age yrs.	No.of rings	Age yrs.	No.of rings	Age yrs.
Total											
No.											
Average											

iii) Age to sections: The time required to reach the height of mid point of each section from the breast height point will be worked out by subtracting the total number of rings on that section from the number of rings on the mid point of the breast height sections. This difference will be the age to sections which are entered in col.3 of Form No.1. Thus the age to mid point of breast height is considered as zero years.

Example: Let there be 72 rings on the breast height sections.

If there are 65 rings at 2nd section, the age of 2nd section will be 72-65 = 7 years.

If there are 62 rings at 3rd section the age of 3rd section = 72-62 = 10 years.

If there are 57 rings at 4th section the age of 4th section is 72-57 = 15 yrs.

This may be entered in col.3 of Form No.1.

24. Marking of Radii:

i) Select 2 radii in each section. Let it be as wide as possible angularly. Let their length be as nearly equal to the calculated average radius as possible (col.8 of Form No.1).

ii) If you are not able to obtain the average radii, select any other normally developed radii so that their sum will be equal to twice the calculated average radii.

iii) If this is not possible, the measurements will have to be subsequently adjusted by multiplying the actual measurements by the adjustment factor (Actual Radius/Average radius).

iv) If the annual rings are not visible along the radii, moisten the surface or chisel the surface.

v) Mark the selected radii on the surface of the sections with a soft pencil and a ruler. Check that they contain the same number of rings.

25. Measurement by Decades on the first section at breast height:

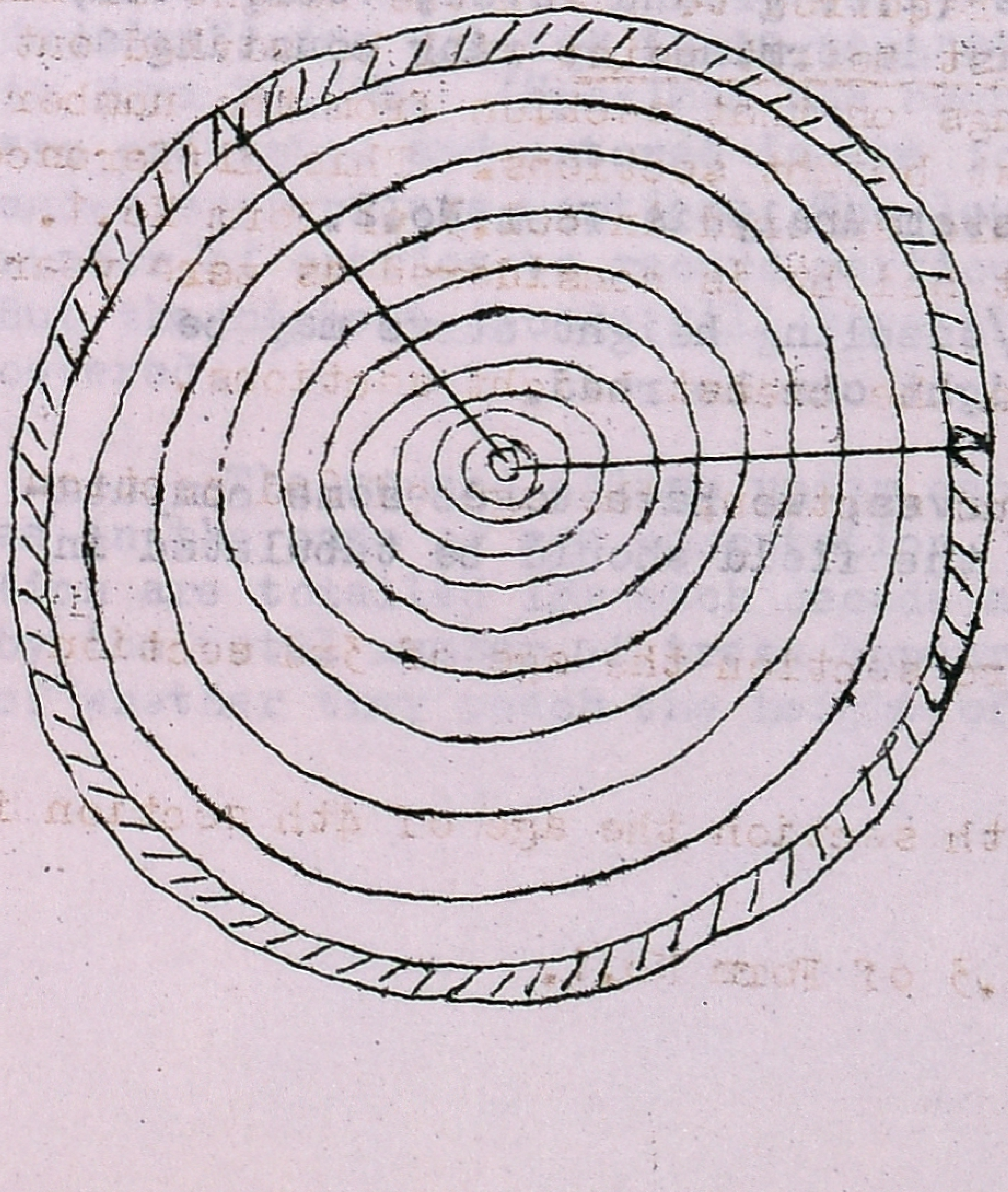
i) Take the first section i.e. breast height section. Mark the decades (10 rings) from the pith outside towards circumference with pins.

ii) So pins will be fixed at every 10th ring from the pith. Check up every ring whether they are complete rings. Do not include incomplete rings and false rings.

iii) Measure the radial length of each decade in cm and mm from pith outwards in one scale setting leaving the incomplete decade at the periphery.

iv) Measurements are entered in the appropriate decade columns in Form No.1.

v) For each decade, there will be 2 readings, corresponding to the 2 radii. Both should be recorded and their total should be entered below them. This total will be the diameter for that decade for the section under analysis.



vi) As told in iii), the incomplete decade is left in the periphery. Their length need not be measured. But the number of odd rings in the incomplete decade should be noted.

Ex: Supposing there are 74 annual rings, you will have 7 decades and 4 rings left in the incomplete decade.

26. Measurements of decades in the 2nd and subsequent sections:

i) On the 2nd and subsequent sections, a number of rings equal to the outermost incomplete decade on the first breast height sections (4 in the above example) should be marked off first counting from the circumference towards the pith and pin inserted at the point on each of the 2 radii. This pin will thus mark off the last decade of the tree.

ii) The remaining rings should be marked off in decades counting from the periphery towards the centre from the outermost pin.

iii) The radial distance is then measured from the pith outward to each pin beginning with the outermost and data entered in the appropriate columns of Form No.1.

iv) Total the pairs of readings for each decade as in the case of breast height section.

v) Please note. Marking of decades on the 2nd and subsequent sections is done from periphery towards the pith after marking off the rings corresponding to the incomplete decade in the first breast height section. The radial length of decades are however measured from pith outwards starting from the outermost pin.

vi) Measure to the nearest mm. The measurements, recorded to other decades are entered in continuation to the right. Measurements of incomplete decade are not recorded.

vii) Take all the readings in one setting of scale.

27. Seedling height data for determining age to breast height:

i) We have to calculate the age to sections in column 4 of Form No.1 considering age at breast height section as zero.

ii) Unless this age at breast height is added we cannot get the full age of the tree. Age at breast height has to be added to each section to get the age of that section. This can be found as follows.

iii) Select 10 to 15 saplings of various heights growing in the open areas of the same site quality.

iv) Their ages at various heights (i.e. ground level, 10cm, 20cm, 30cm, 80cm, 130cm, 150cm heights) are determined by ring counting at the required heights.

v) Data may be recorded in the stem Analysis Form No.2.

vi) From the average values, age/seedling height curve may be plotted from which age at breast height can be read.

COMPUTATIONS: Before drawing the curves, we have to do some computations. Hence the data collected in the field should be tabulated in the respective forms.

28. Age computations (Please see Form No.1):

i) Col.2 and 3 of stem analysis Form No.1 give the height of each section and age above breast height to reach the given sectional height. The number of years taken to grow from the breast height to the heights of successive sections should be determined by subtracting the number of rings on the section from the number of rings at breast height. This number is filled in col.3 of Form No.1. For this we assume the age at breast height as zero. There will be 86 rings in this section. The next section may have 82 rings. Deduct 82 from 86. This 4 will be the age of next section. Similarly if there are 75 rings in the 3rd section, its age will be 86-75 = 11 years. If there are 65 rings in the 4th section the age will be 86-65 = 21 years. These data may be abstracted, classified and entered in Stem Analysis Form No.3(a).

ii) Before totalling and averaging, any tree which appears (from its measurements) abnormal, or very slow growing, should be excluded from calculation.

iii) In some trees, the topmost section may not be of standard length. Hence there will be a deviation. Supposing the height of the mid point of last section is 35m instead of 34.24m, then there may be a deviation in the last section from the standard height. It is +0.76m in this case. This should be entered in the " Deviation column " in the last section.

Similarly if the height of last section is 34m instead of 34.24m. there is a deviation of -0.24m.

iv) While totalling the deviation columns of Form 3(a), + and - signs should be considered and they should be algebrically added and it should be divided by the total number of entries for that sectional height class and not by the number of deviations. See example in the Form 3(a).

v) The average deviation will be added or subtracted from the last standard height as its sign may be + or - before plotting.

29. Mean Diameter Computation for decades: The diameter under bark at different heights has been entered in the Form No.1 (which is a totalled figure of 2 radius - found under " radius at successive decades") for all the trees separately for such decade and entered in Form No.3-B. (Specimen has been given). Diameters of one decade are collected and entered in the form against the particular tree under appropriate sections. The lower decades will have lesser number of entries to record particularly under fewer height sections. But the highest decade will have the maximum number of height sections covered.

The second column under each height section is of deviation as in the case of age computation. The diameter U.b. and the deviation are totalled for each decade and averaged by dividing the total by the total number of trees appearing in that decade, irrespective of whether they reach the height of the section or not.

STEM ANALYSIS FORM No.3a

AGE COMPUTATIONS

Species: Division:

Quality: Block & Compartment:

Tree No.	1.37 Age	Dev.	4.24 Age	Dev.	7.24 Age	Dev.	10.24 to 22.24	25.24 Age	Dev.	28.24 Age	Dev.	31.24 Age	Dev.	etc.
	Height of sections in metres													
1	0		4		11			78	-2	..		..		
2	0		7		12			57		70		95	+1½	
3	0		5		11			60		80	-1	..	..	
4	0		8		13			85	+1½	..	..	..	..	
5	0		6		9		etc. etc.	70		80		91	-1½	
Total			30		56			350	-½	230	-1	186	0	
No. of observations			5		5			5	5	3	3	2	2	
Average			6		11			70	-0.1	77	-0.3	93	0	

STEM ANALYSIS FORM 3b

MEAN DIAMETER COMPUTATION FOR DECADES

Species: Division:

Quality: Block & Compartment:

Tree No.	1.37 Dia.	1.37 Dev.	4.24 Dia.	4.24 Dev.	7.24 Dia.	7.24 Dev.	10.24 to 25.24	28.24 Dia.	28.24 Dev.	31.24 Dia.	31.24 Dev.
							Decade 10				
1.	12.9		7.5								
2.	13.2		6.0								
3.	10.2		5.1								
4.	10.8		2.4								
5.	14.4		7.8								
Total	61.5		28.8								
No.	5		5								
Av.	12.3		15.7								
							Decade 20 to Decade 70				
1.											
2.											
3.											
4.											
5.											
Total											
No.											
Av.											
							Decade 80				
1.	55.5							0.9	-2	0	
2.	65.4							12.0		2.1	
3.	69.9		etc.		etc.			7.5		0	
4.	71.1							0		0	
5.	76.5							6.9		0	
Total	338.4							27.3	-2	2.1	
No.	5							5	5	5	
Av.	67.6							5.4	-0.4	0.4	

Height of Section in Metres

30. Mean Tree Volume Computation for Decades:

i) We have to calculate the volume of mean tree of each decade.

ii) For this the diameter is obtained from curve 4 which is the d.u.b./height curve separately for each decade.

iii) Take curve for each decade. Read the diameters at 1.37m, 4.24m, 7.24m, 10.24m, 13.24m and so on.

iv) Find out the basal areas for all these diameters from the table giving areas of circles for given diameters.

v) The basal area may be multiplied by the length of the section. This will give the volume.

vi) Adopt this procedure for all sections except the last which is regarded as cone.

vii) The uppermost section is a cone. The basal diameter will be obtained by reading the top end diameter of the previous sections from the d.u.b. - height final curve (curve 6 - Step III) against the height of the top end point (not mid section) of the previous section. See specimen data in the Form 3. The last section of the tree for decade 10 is a 2 feet cone. The height of the top end of the previous section is 19 feet. The d.u.b. against 19 feet from the curve is 0.5 feet. So 0.5 feet is the basal diameter of cone. Similarly, for decade 20, the height of last section is 3 feet whose basal diameter (i.e., the diameter of the top end of the previous section which is at a height of 39 feet) as read from the graph is 1.0 foot.

viii) Basal area is multiplied by section lengths to get volume. But for last section volume of cone is calculated with formula 1/3 basal area x height.

ix) All these details are filled up in Form 3c. The volumes of all sections are added decade-wise to get the volume of the mean tree by decades.

31. Computation for Bark Thickness:

i) In the stem analysis Form 1 col.7 gives the Twice bark thickness and col.6 gives d.u.b. for each section of every tree analysed. This data is abstracted from Form No.1, arranged in diameter classes of say 10 cm and tabulated in Stem Analysis Form No.4.

ii) The d.u.b. and twice bark thickness in Form 4 are then totalled and averaged.

DRAWING OF CURVES: With the help of computed data, following curves will be drawn.

32. Curve 1: Age/height of Seedlings:

i) Please read para 27. This curve is drawn to find out the age at breast height so that this can be added to the age of other sections to find out the total age of those sections.

[Contd in p 211

STEM ANALYSIS FORM 3c

MEAN TREE VOLUME COMPUTATIONS BY DECADES

Species: Division:

Quality :   Block & Compartment:

	Height of Sections in metres					
	1.37 or 4½'	4.24 or 14'	7.24 or 24'	10.24 or 34'	13.24 or 44'	16.24 to 34.24 etc. etc.
			Decade 10			
Diameter	4.1	1.9	2'cone 0.5			
Basal area	0.0917	0.0917	0.0014			
			Total Volume 1.02			
Volume	0.8523	0.1970	0.0009			
			Decade 20			
Diameter	8.3	6.6	4.7	2.4	3'Cone 1.0	
Basal area	0.3758	0.2376	0.1205	0.0314	0.0055	
Volume	3.3822	2.3760	1.2050	0.3140	0.0055	
			Total volume = 7.28			
			Decade 30			
Diameter						
	(Note: Example given in feet and inches)					
Basal area		etc.		etc.		etc.
Volume		etc.		etc.		etc.

STEM ANALYSIS FORM No.4

COMPUTATIONS FOR TWICE BARK THICKNESS

Species:

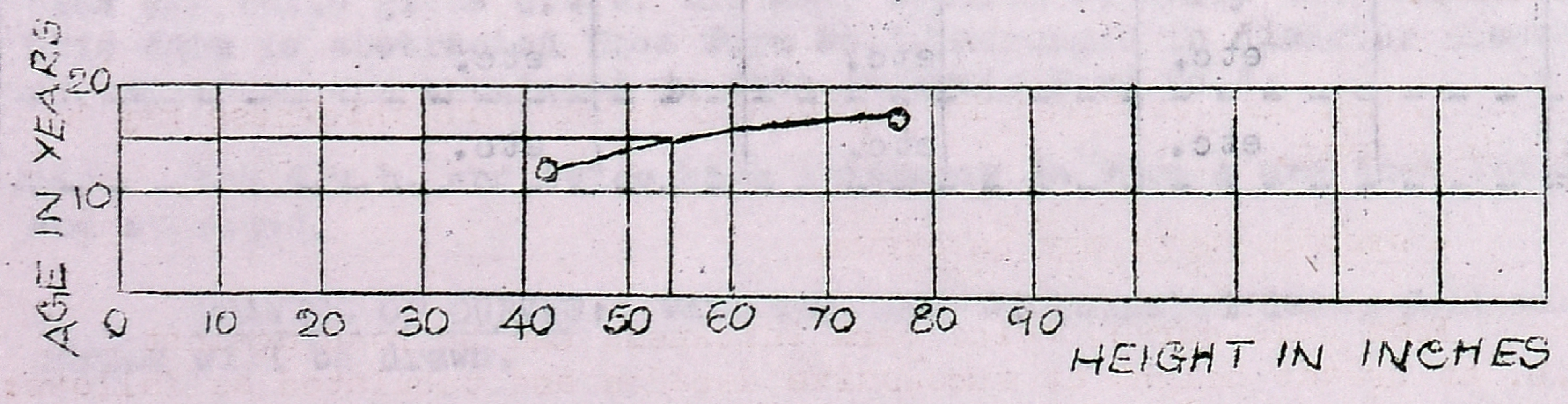
Quality: Division:

Crown Class: Block & Compartment:

	Diameter classes (cm)								
	0 - 10		10.1-20		20.1 - 30		30.1 - 40		
	d.u.b.	T.B.T	d.u.b.	t.B.T	d.u.b.	T.B.T	d.u.b.	T.B.T.	etc., etc.
Total									
Number									
Average									

Age/Height of Seedlings

Curve No.1

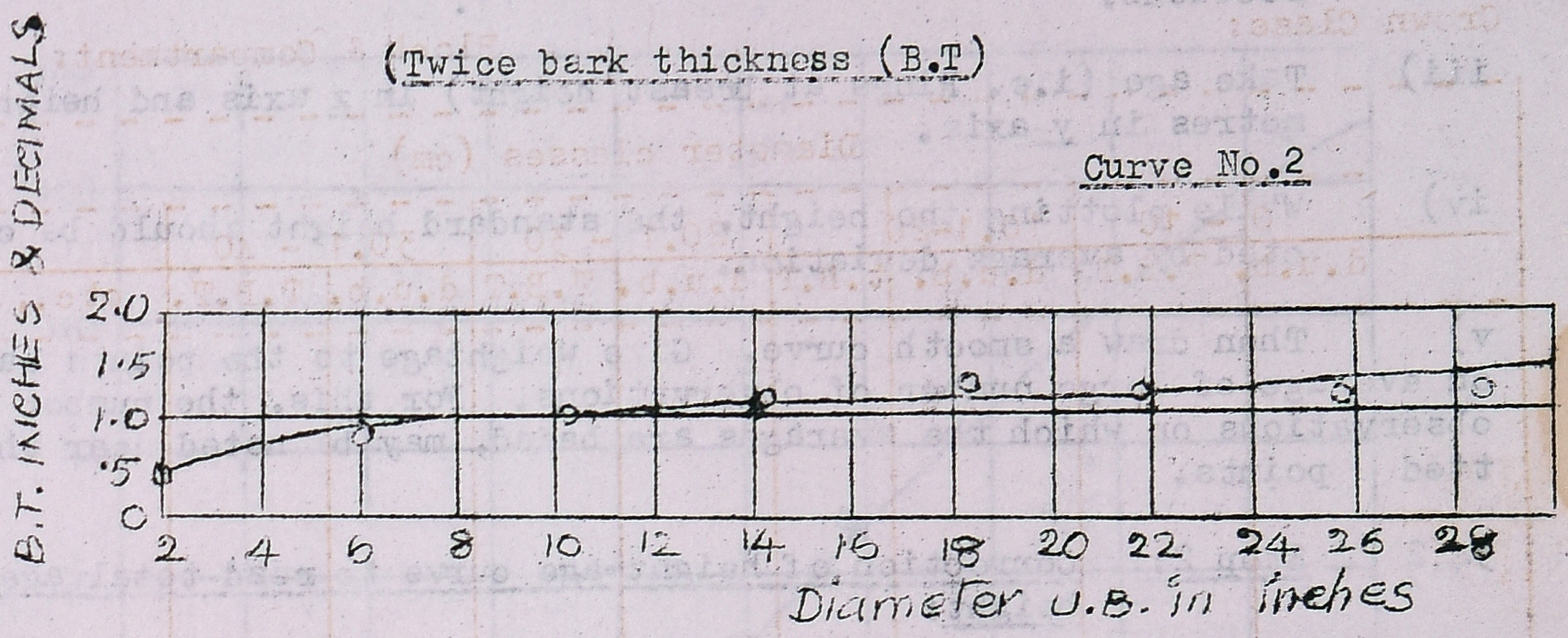


STEM ANALYSIS

Species: Picea morinda Division: Chakrata

(Twice bark thickness (B.T)

Curve No.2



ii) Please see Form No.2. You will have average ages and heights of seedlings in term of 10cm diameter classes.

iii) These ages are plotted against corresponding average heights and a smooth curve is drawn. Take height in x axis and age in y axis.

iv) Read out the average age from this curve to the breast height.

33. Curve No.2: D.O.B./Twice bark thickness Curve:

i) Please read para 22 iv) in which you have computed the Twice Bark Thickness and entered in col.17 of Form No.1.

ii) Please read para 31. You have entered the d.u.b. and Twice Bark Thickness in Form No.4.

iii) The average values of D.U.B may be plotted against Twice Bark Thickness.

iv) D.U.B. may be taken in x axis and twice bark thickness may be taken in y axis.

v) A smooth curve may be drawn.

vi) From this curve, twice bark thickness can be read against d.u.b. at breast height at successive decades and tabulated as follows:

vii) d.b.h.u.b. + Twice Bark Thickness = DBH (O.B.)

Age	d.b.h. (U.B)	Twice bark thickness	D.b.h.(O.B.)
10	20	3	23
20	25	3.5	28.5
30	35	4.0	39.0
40	-	-	-
50	etc.	etc.	etc.
etc.			

34. Curve No.3: Age/height curve:

34.1 Step 1:

i) Please see para 28 and Form 3(a).

ii) The average age is plotted against corresponding height of sections.

iii) Take age (i.e. Rings at breast height) in x axis and height in metres in y axis.

iv) While plotting the height, the standard height should be corrected by average deviation.

v) Then draw a smooth curve. Give weightage to the points based on average of large number of observations. For this, the number of observations on which the averages are based, may be noted near the plotted points.

34.2 Step 2: Correction of height-age curve to read total age-height:

i) The average ages on x axis denote the ages above the breast height. But we want the total age.

ii) You have assumed the age at breast height as zero originally.

iii) You would have already read the age i.e. number of years taken for the tree to grow upto breast height from curve 1 - see paragraph 32.

iv) Hence the age in x axis may be shifted to the left by the necessary units which represent the period taken by the tree to grow upto breast height (Please see curve No.3 where the age has been shifted to the left).

v) The shifted points are the new points which give the total age of the trees at various heights.

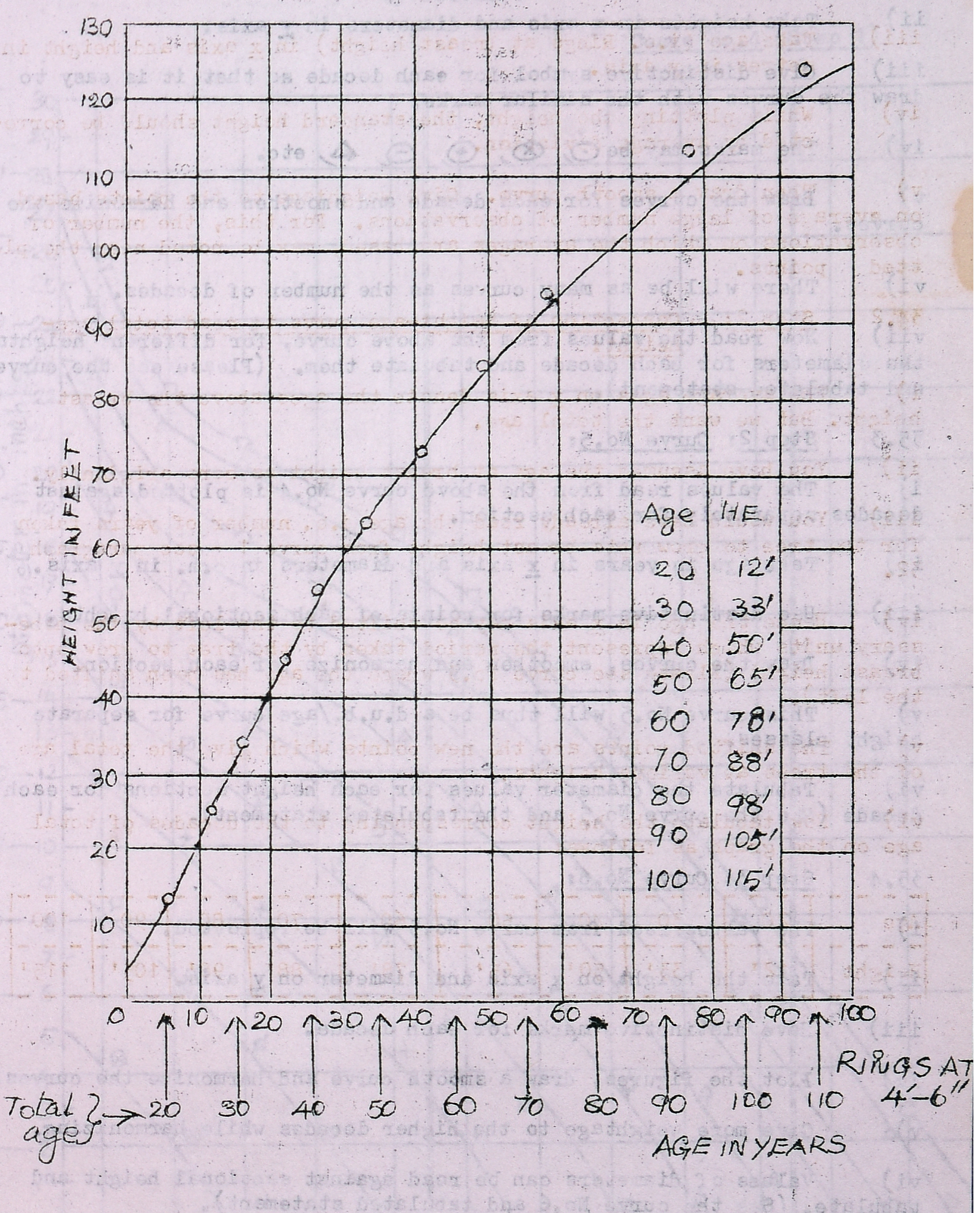
vi) Now tabulate the height corresponding to the decades of total age on the graph as follows:

Age	20	30	40	50	60	70	80	90	100
Height	12'	33'	50'	65'	78'	88'	98'	105'	115'

STEM ANALYSIS

Species: Picea morinda Division: Chakrata

Height/Age Curve No.3



Age-Diameter (U.B) Curve (Curves 4 to 6)

35.1 This curve will have to be drawn in several stages. Please see Form 3(b) i.e. mean diameter computation for decades. The average values of d.u.b. obtained from a series of Form 3b should be

plotted against corresponding heights of sections separately for each decade and the curves smoothened and harmonized. This can be done in the following 3 steps.

35.2 Step 1: Curve No.4:

i) Average diameter should be plotted against height of section for each decade.

ii) Take heights in x axis and diameters in y axis.

iii) Give distinctive symbol for each decade so that it is easy to draw the curves with the similar marks.

iv) The marks may be ⊙, ⊗, ⊕, ⊖, △, etc.

v) Draw the curves for each decade and smoothen and harmonize the curves.

vi) There will be as many curves as the number of decades.

vii) Now read the values from the above curve, for different heights, the diameters for each decade and tabulate them. (Please see the curve and tabulated statement).

35.3 Step 2: Curve No.5:

i) The values read from the above curve No.4 is plotted against decades separately for each section.

ii) Take age in years in x axis and diameters in c.m. in y axis.

iii) Use distinctive marks for points of each sectional heights.

iv) Draw the curves, smoothen and harmonize for each section.

v) This curve No.5 will thus be a d.u.b./age curve for separate height classes.

vi) Tabulate the diameter values for each height sections for each decade (See the curve No.5 and the tabulated statement).

35.4 Step 3: Curve No.6:

i) The values read from curve No.5 will be replotted.

ii) Take the height on x axis and diameter on y axis.

iii) Have distinctive marks for each decade.

iv) Plot the figures, draw a smooth curve and harmonize the curves.

v) Give more weightage to the higher decades while harmonizing.

vi) Values of diameters can be read against sectional height and tabulate. (See the curve No.6 and tabulated statement).

Contd in P 220

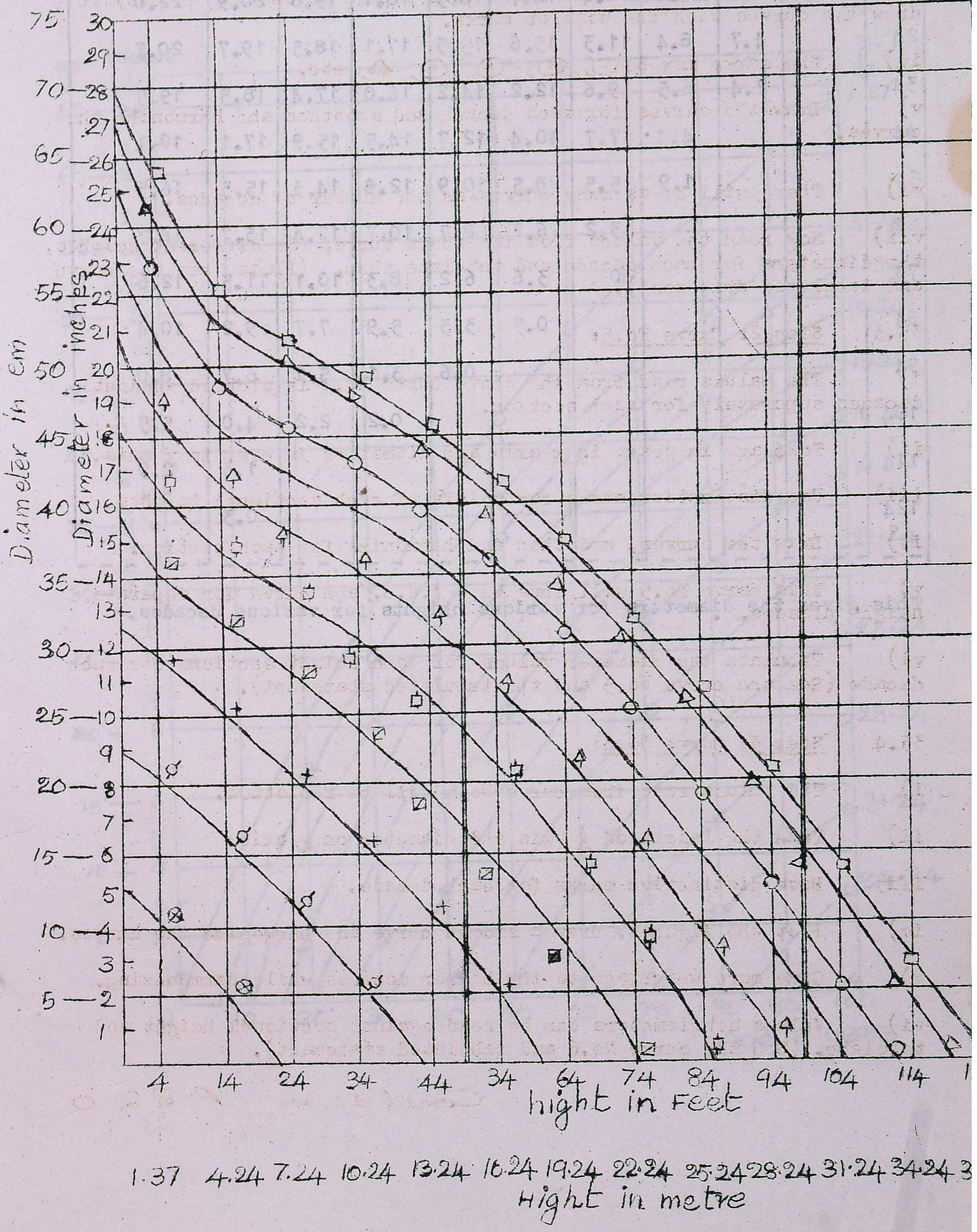
STEM ANALYSIS

Species: Picea morinda

Division: Chakrata

Diameter under bark/Height (First Curve)
by decades.

Curve No.4 (Step 1)



	⊠	ø	+	▱	⊘	△	×	○	△	▭
Ht. feet	10 yrs.	20 yrs.	30 yrs.	40 yrs.	50 yrs.	60 yrs.	70 yrs.	80 yrs.	90 yrs.	100 yrs.
4½	4.1	8.3	11.6	14.4	16.9	18.9	20.8	22.6	24.1	25.4
14	1.9	6.6	10.1	12.6	14.7	16.5	18.1	19.6	20.9	22.0
24		4.7	8.4	11.3	13.6	15.5	17.1	18.5	19.7	20.7
34		2.4	6.5	9.6	12.2	14.2	16.0	17.4	18.5	19.5
44			4.4	7.7	10.4	12.7	14.5	15.9	17.1	18.1
54			1.9	5.5	8.5	10.9	12.8	14.3	15.5	16.5
64				3.2	6.2	8.7	10.7	12.4	13.7	14.7
74				0	3.6	6.2	8.3	10.1	11.5	12.6
84					0.5	3.5	5.9	7.7	9.2	10.4
94						0.6	3.1	5.1	6.7	8.0
104							0.2	2.2	4.0	5.5
114									1.3	2.9
124									0.3	

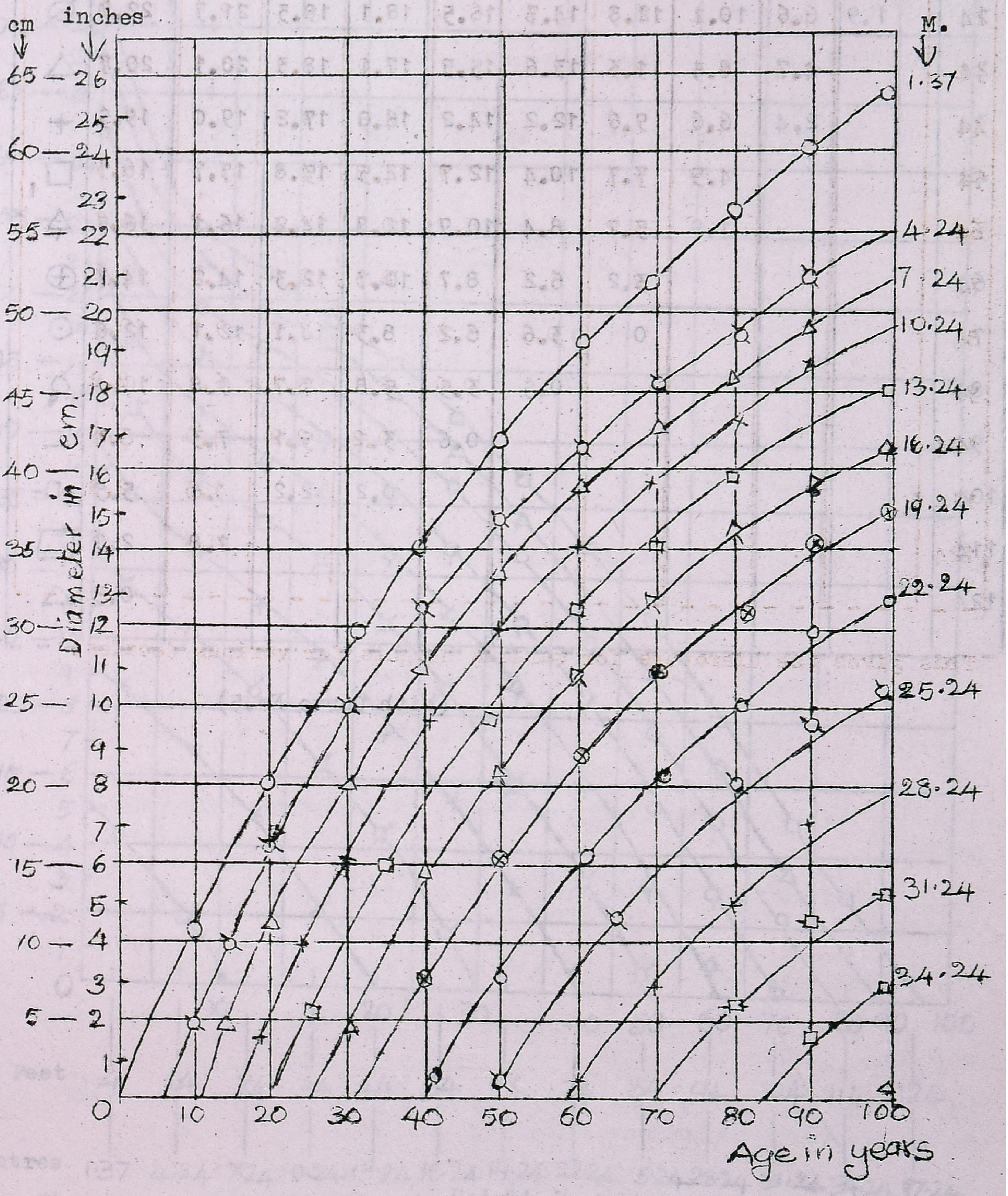
This gives the diameters for various heights for various decades.

STEM ANALYSIS

Species: Picea morinda Division: Chakrata

Diameter under bark/Height (Second Curve)

Curve No.5 (Step 2)



From Curve 5

Ht.	10	20	30	40	50	60	70	80	90	100	
4½	4.1	8.3	11.8	14.4	16.6	18.9	20.8	22.6	24.4	25.4	○
14	1.9	6.6	10.1	12.8	14.7	16.5	18.1	19.3	21.3	22.0	⊘
24		4.7	8.4	11.3	13.6	15.5	17.1	18.3	20.1	20.7	△
34		2.4	6.6	9.6	12.2	14.2	16.0	17.2	19.0	19.5	+
44			4.5	7.7	10.4	12.7	14.5	15.8	17.7	18.1	□
54			1.9	5.7	8.4	10.9	12.8	14.2	16.1	16.5	△
64				3.2	6.2	8.7	10.7	12.3	14.2	14.7	⊕
74				0	3.6	6.2	8.3	10.1	12.1	12.6	⊙
84					0.5	3.5	5.8	7.7	9.8	10.4	○
94						0.6	3.1	5.1	7.3	8.0	—
104							0.2	2.2	4.6	5.5	-□-
114									1.8	2.9	□
124										0.3	△

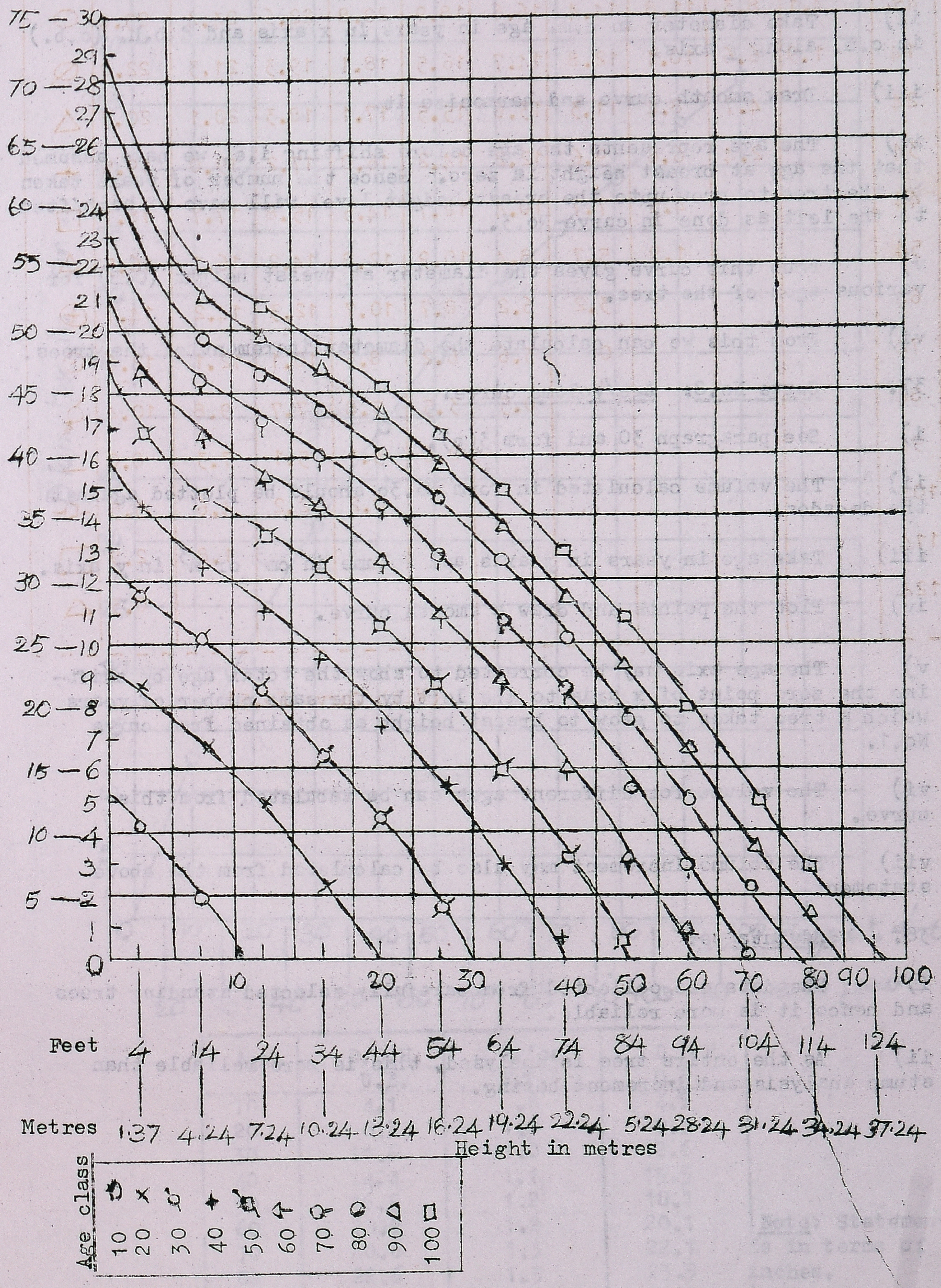
(With Curve No.5)

STEM ANALYSIS

Species: Picea morinda   Division: Chakrata

Diameter under bark/height (Final curve)

Curve No.6 (Step 3)



35.5 Thus curve No.6 gives d.u.b. at different heights for each decade. These data can be utilised for drawing a age/d.o.b. at breast height curve. But this curve gives us only d.u.b. Bark thickness for various d.o.b. have been worked out already in para 33 and curve No.2. Hence D.O.B at breast height can be calculated.

36. **Curve No.7: Total age/D.B.H.(O.B) Curve:**

i) The d.b.h. (u.b.) obtained from para 33 and curve No.2, is plotted against their respective ages.

ii) Take diameter in c.m. age in years in x axis and d.b.h. (o.b.) in c.m. along y axis.

iii) Draw smooth curve and harmonize it.

iv) The age represents the age before shifting i.e. we have assumed that the age at breast height is zero. Hence the number of years taken by the tree to grow upto the breast height level will have to be shifted to the left as done in curve No.3.

v) Thus this curve gives the diameter at breast height (O.B) for various ages of the tree.

vi) From this we can calculate the diameter increment of the trees.

37. **Curve No.8: Age/volume curve:**

i) See paragraph 30 and form 3(c).

ii) The volume calculated in form No.3c should be plotted against the decades.

iii) Take age in years in x axis and volume in cm^3 or m^3 in y axis.

iv) Plot the points and draw a smooth curve.

v) The age axis may be corrected to show the total age by shifting the zero point of x axis to the left by the same number of years which a tree takes to grow to breast height as obtained from curve No.1.

vi) The volume for different ages can be tabulated from this curve.

vii) The volume increment may also be calculated from the above statement.

38. **Advantages:**

i) The data are collected from carefully selected standing trees and hence it is more reliable.

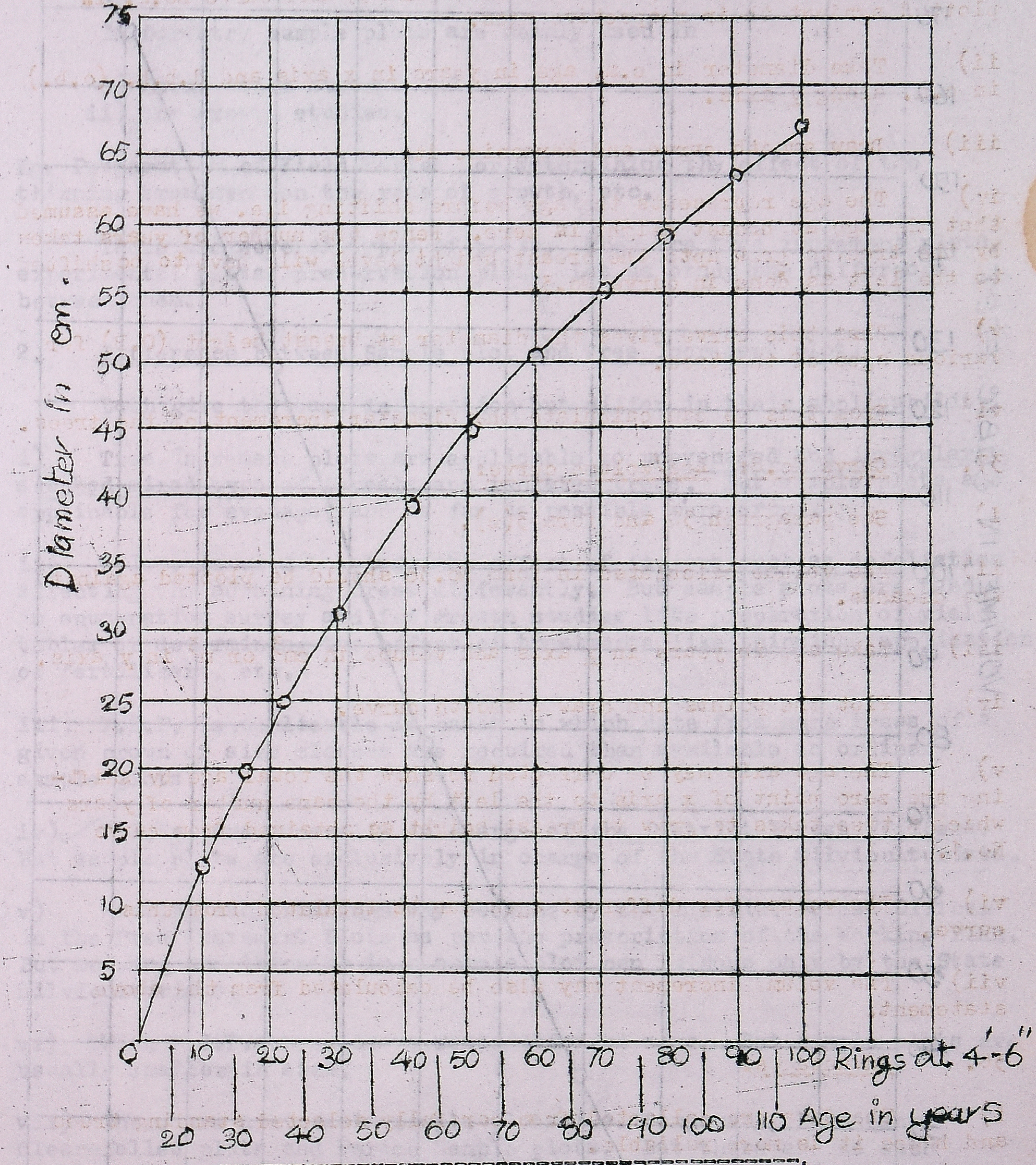
ii) As the entire tree is analysed, this is more reliable than stump analysis and increment boring.

STEM ANALYSIS

Species: Picea morinda Division: Chakrata

D.B.H. (over bark)/Age

Curve No.7



Age	D.B.H. U.B.	Twice B.T.	D.B.H. O.B.
10	4.1	.8	4.9
20	8.3	1.0	9.3
30	11.6	1.0	12.6
40	14.4	1.1	15.5
50	16.9	1.2	18.1
60	18.9	1.2	20.1
70	20.8	1.3	22.1
80	22.6	1.3	23.9
90	24.1	1.4	25.5
100	25.4	1.4	26.8

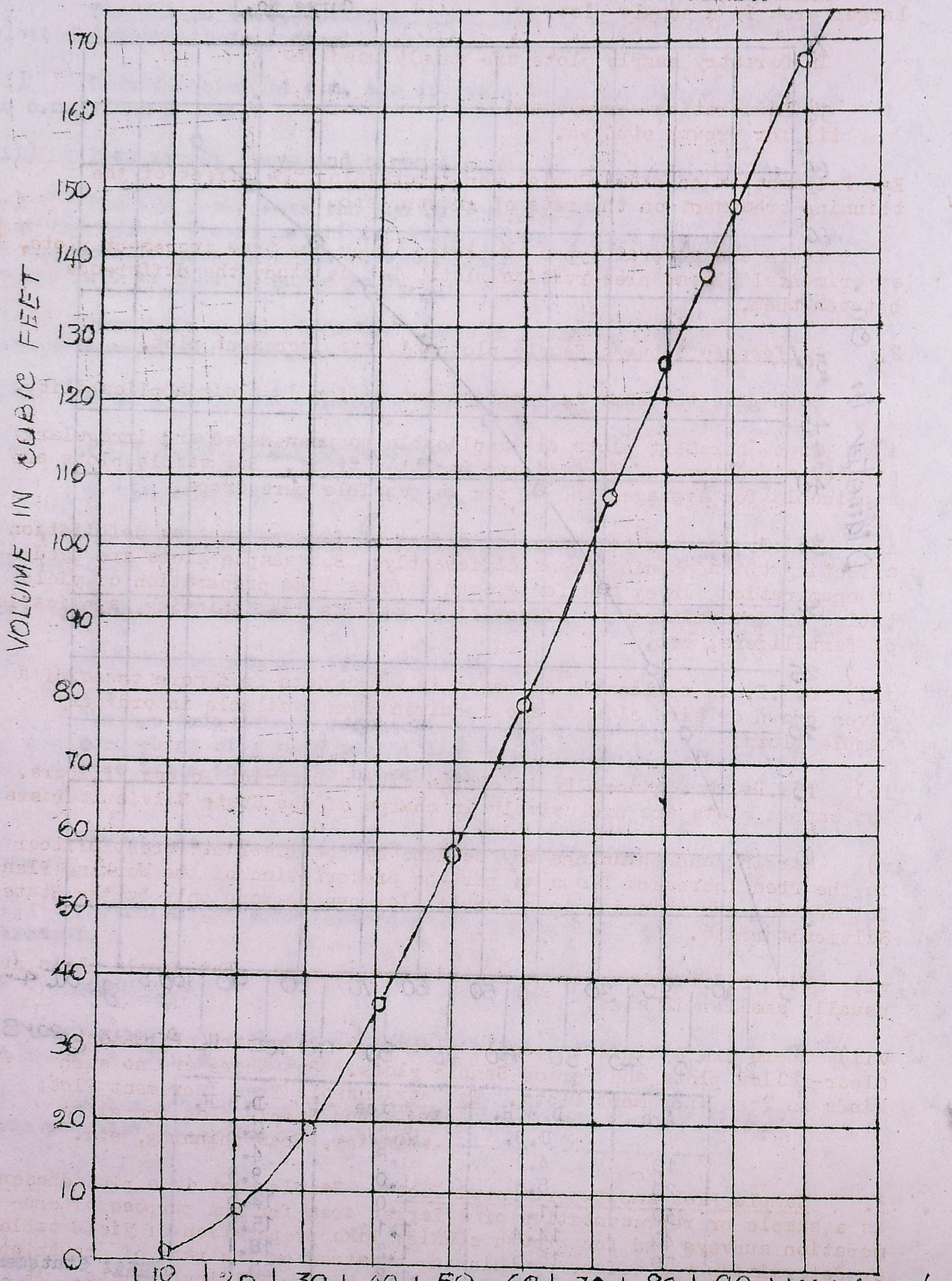
Note: Statement is in terms of inches.

iii) It gives complete information about the growth of trees in respect of diameter, height and volume and hence it is self-contained.

STEM ANALYSIS

Species: *Picea morinda* Division: Chakrata

Volume Curve Curve No.8



CHAPTER XII

SAMPLE PLOTS

1. Definition: A plot chosen as a sample or representative of a larger area is a sample plot.

In forestry sample plots are mainly used in

i) Enumeration surveys and
ii) for growth studies.

Eg. Preparation of Yield Tables, or determining the effect of the thinning treatment on the rate of growth, etc.

There are several types of plots. They are tree increment plots, experimental plots, preservation plot. Let us study the difference between them.

2. Difference between Sample plot and Tree Increment plot.

Both give the same information but differ in their applicability.

i) Tree Increment plots are applicable to unevenaged and irregularly stocked mixed type of forests and isolated trees. But sample plots are applicable for evenaged and as far as possible pure crops.

ii) T.I.P. is used to study the effect of factors such as defoliation affecting the adjoining trees differently. But sample plots are used in enumeration survey and for growth studies like preparation of yield tables or determining the effect of treatments like thinning, application of fertilizers, etc.

iii) T.I.P. is applicable in cases in which data from more trees of a given crown or size classes are required than available in ordinary sample plots.

iv) T.I.Ps. are generally in charge of the District Forest Officers. But sample plots are exclusively in charge of the State Silviculturists.

v) Marking and thinnings may be done by the District Forest Officer in the Tree Increment Plots as per the prescription of the Working Plan. But marking and thinning in a sample plot can be done only by the State Silviculturists.

vi) With T.I.P. there is no restriction of size. But sample plots are usually smaller in size.

vii) There are 4 kinds in sample plots i.e. Temporary, Permanent, Clear-felled plots and Period Sample plots. But there are no such kinds in Tree Increment Plots. Eg. Karianshola Tree Increment Plot; Nilambur Sample plot for elite thinning, free thinning, etc.

3. Sample Plot and Experimental Plot: Sample plot is a plot chosen as a sample or representative of a larger area for the purpose of enumeration surveys and for growth studies like preparation of yield tables or determining the effect of thinning treatment on the rate of growth, etc. It has several kinds. They are maintained by the Silviculturists. It

gives very many information. Periodic measurements are taken once in 5 or 10 years.

But experimental plot is an area laid out to determine the effects of a certain method of treatment (e.g.) experiments for finding out optimum spacing; to select best kind of material; to select best time of sowing or planting; select the best watering regime; select best type of earthwork like pits, saucers, trenches, etc; to select the best size of pits or trenches, etc. Here growth studies is not the ultimate objective of the experiments. But the object is only to find out the best possible technique of planting that can be followed under a given set of conditions.

Example: Experimental plots seen in Theri and Rameswaram.

Both sample and experimental plots have to be designed.

Design is a method of arranging sample or experimental plots to minimise the effects of uncontrolled variations in fertility and other natural factors to make it possible to estimate the magnitude of such effects in relation to those due to variations in treatment (i.e. to controlled variations).

4. Sample Plot and Preservation Plot: A Preservation Plot is a sample area of natural forest or plantation set apart for preservation in perpetuity - mainly for the purposes of ecological observations and growth studies covering the full life of the trees or crops.

(Eg.) Preservation Plot areas - Staircase Shola of Nilgiris, etc., Canolly's Teak plantation in Nilambur Division.

5. Object of Sample Plots:

i) To do enumerations.

ii) Determination of crop volume and crop increment at all stages of development of evenaged crops.

iii) Preparation of Yield Tables.

iv) Comparison of growth in different qualities of locality.

v) Finding out the effects of certain treatments such as grades or intensity of thinning, application of fertilizer, etc.

6. Kinds of Sample Plots: Mainly there are 2 kinds of Sample Plots. They are

a) Permanent Sample Plots
b) Temporary sample plots.

All are located only in regular crops.

a) Permanent Sample Plots: They are established in young evenaged woods and measured at intervals of usually 10 years upto rotation age - depending upon the rate of growth. Laying out should be done when the crop is very young - preferably before the first thinning. As these plots have to be maintained for a long time, they are called as Permanent Sample Plots. The same trees or the trees of the Sample Plot are subject

to measurement and hence the growth studies will be more accurate. These results can be applied for the future crops.

b) Temporary Sample Plots are selected covering the whole range of age gradations. Measurements are taken only once. The results obtained from measurements from various sample plots are graphed and conclusions deduced. Hence, results are obtained quickly and hence can be made use of for speedy compilations of Yield Tables, etc.

7. Additional Categories of Sample Plots: Following are the additional categories of sample plots. They are

7.1 Clear-felled Plots: Measurements are taken in clear-felled plots - only once - after felling. As the whole trees are accessible for being measured, these measurements are more accurate. But we cannot clearfell the area for the purpose of measurements.

7.2 Period Sample Plots: We saw that Permanent Sample Plots give more accurate results after long time and Temporary Sample Plots give results quickly - but not very accurate. Period sample plot is a mean between Temporary and Permanent Sample Plots. This gives fairly accurate results. We need not wait for a long period. A number of sample plots are selected, differing in age by a number of years - say 30 years and from all the plots, series of measurements are obtained for the entire rotation period. Supposing, Yield Tables has to be prepared for a particular species of rotation of 120 years, and the period chosen is 30 years, then Sample Plots are selected in plots of ages of 10 years, 40 years, 70 years, 100 years. The time schedule of measurements will be as follows:

Time of measurement	First Plot	2nd Plot	3rd Plot	4th Plot
1st measurement say 1970	10 yrs.	40 yrs.	70 yrs.	100 yrs.
2nd measurement 1980	20 yrs.	50 yrs.	80 yrs.	110 yrs.
3rd measurement 1990	30 yrs.	60 yrs.	90 yrs.	120 yrs.

Care should be taken to see that the various period sample plots are all in the same quality class. These plots are semi-permanent plots. Laying out the Sample Plots and taking measurements will be the same as in the case of Permanent Sample Plots. Hence they are sometimes recognised as permanent sample plots and their separate identity not recognized.

8. Uses of Sample Plots: All the above kinds of Sample plots are useful for the following purposes:

i) Estimation of volume and increment of standing crops.

ii) Collection of data for compiling Yield Tables.

iii) Determining the crop volume and crop increment at all stages of development of evenaged crops.

iv) Comparison of crop volume and crop increment of evenaged crop of the same origin and treatment on different qualities of locality.

v) Comparison of influence on crop volume and crop increment in evenaged crops of different methods of regeneration and treatment.

vi) To study the degradation or improvement of site after several rotations.

vii) To study the effect of espacement, thinning treatment and provenance on the properties of the timber produced.

Note: Provenance is the geographical source or place of origin from which a given lot of seeds or plants were collected.

9. Selection of Plots:

i) Plots should be laid out in evenaged crops.

ii) Selected plots should be as fully stocked as possible.

iii) If fully stocked plots are not available, they should atleast be uniformly stocked.

iv) Trees at the edge of the crop or with crowns spreading into a gap should not be included in the plots.

v) For Yield Tables, they should be selected in crops of all ages and should be distributed over the wide range of quality, type and geographical distribution of the species.

vi) Plots should be selected in pure crops. But plots may also be selected in mixed crops where such mixtures are of common occurence and importance.

10. Number of Plots required: This will depend upon the number of age classes and number of quality classes proposed and the variations in the treatments particularly the thinnings. For each decade in each quality per each thinning regime, there should be a minimum of two plots.

For example, for preparation of Yield Tables for Teak for a rotation of 80 years and with 4 quality classes and only one thinning regime, there should be at least 64 plots (8 x 4 x 2). But in practice we can have 100 sample plots to make up for the irregularity of distribution, stocking, etc. The number of plots in the best and worst qualities should be proportionately more as the trend of quality classes curve will be indicated by limiting curves on either extreme.

11. Shape of Plots: It may be circular, triangular, square or rectangular. Circular plots are easier to lay of all the geometrical figures; a circle encloses the largest area for the same perimeter and theoretically it has the least number of boundary line trees. Circular plots of 0.1 Ha. (radius 17.84 M) can be used. But in

(r = 17.84 m) No. of Plots = No. of decade x No. of quality class x 2

practice, it is easier to lay straight lines rather than a circle. In India, mostly rectangular plots are laid. The actual length of sides and diagonals and their slope are measured and recorded on a digramatic sketch map for purposes of calculation of the area.

12. Size of Plots: It should neither be too small nor too big. A plot should be of 0.1 to 0.2 Ha.

13. Lay out of Plots: The lay out of plot includes laying out a surround, demarcation of plot boundary, marking the cross marks, numbering of trees in the plot and preparing a plot chart showing lay-out of plot and trees in it.

13.1 The Surround is defined " as an area maintained round an experimental or sample plot to ensure that the latter is not being affected by the treatment applied to the area outside them both." It is also known as isolation or buffer strip.

This strip should be of sufficient area. This area will have similar type of growth and will be treated in the same manner. The object is that the edge of the forest grows under the same conditions as that of the plot. We can select some sample trees from the surround also if such trees are not available within the plot. It ensures uniformity of treatment and protection from felling, in the surrounding forests. The surround need not be of even width. But in an average the width should be equal to the height, the crop is expected to reach by the end of the study. Minimum width should be of 15m.

13.2 Demarcation and Numbering:

a) The whole area including the surround is demarcated. This is done by painting white rings at breast height on a few outermost trees. All possible projections of the crowns of border trees should fall within the plot.

b) The boundary lines are demarcated by fixing durable wooden posts or stone pillars or R.C.C. pillars serially numbered. These posts are planted at the corners.

c) Trenches of 30cm wide and 30cm deep are dug all along the boundaries. Otherwise lock pits of 45cm deep and 30cm wide may be dug out extending upto half the distance of the sides or lock pits may be dug for 1m long on both sides of the corners.

d) If erosion is feared, trenches need not be dug - but durable wooden posts may be fixed at every 4m or 6m all along the boundary line.

e) All the trees in the surround should be painted with white rings, at breast height.

f) A name board, indicating the number of plot and year of formation - should be fixed at a convenient and conspicuous place in or near the plot.

g) Permanent Sample Plots should be serially numbered separately for each division. These numbers should never be changed even if some sample plots have been abandoned.

h) Temporary plots should also be given serial number for each species in each division.

14. Initial Treatment of the Crop: After laying out the plot, the crop should be given the desired treatment before taking the first measurement. In India, a thinning is given to the plot to bring it to normal conditions. The number of stems to be retained will be as indicated by n/D curve in the Yield Table for the fractional quality of the locality in question. It is generally thinned to 'C' grade or 'D' grade ordinary thinning. If the plot is overstocked, it is thinned to bring the normal stock corresponding to C grade. The understorey, unless necessary, is retained. The work done is correctly recorded in the Sample Plot file.

15. Cross Marks and Numbering: All the green trees included within the limits of the plot and whose measurements are to be recorded are painted with a cross-mark at breast height - i.e., the position where the diameter or girth is to be measured. If it is a sloping ground, the cross marks will be at breast height as measured in the uphill side. In level grounds it should face in the same way. All cross marked trees above 10cm in diameter should be serially numbered, with white paint. The numbers should be written at a place 15cm above the cross mark. In hilly areas the numbering will start from above and proceeded stripwise along the contour. In level grounds, it will be in strips parallel to one of the sides of the plot. Cross marking and numbering should be done after removing dead bark with a sharp instrument to give a smooth surface for painting. Care should be taken not to injure any living tissue. If it is difficult to do the painting, the numbers may be written on a metal plate and hung in a springed ring attached to the tree, as used in K.F.R.I., Nilambur. This facilitates the expansion of the tree without damaging the tree when it grows. All unnumbered trees are enumerated.

16. Measurement of standing Crop: Breast height measurements of each tree painted with cross marks is measured with callipers and recorded in the form. The unnumbered trees are enumerated in 2 cm diameter classes and recorded in the same form. Diameter of trees to be thinned at first measurement should be recorded separately. Particulars of trees removed in subsequent thinnings are entered in the same form. Crown classes should be recorded for every tree for which diameter is recorded separately.

17. Selection of Sample Trees: Sample trees should be selected from amongst the trees to be thinned in the sample plot proper. If sufficient number of trees are not available from the sample plot, they may be selected from the surround. Before selecting sample trees for the main crop, height of an adequate number of trees, not less than 12, of typical trees standing inside the plot and distributed over the complete height and diameter ranges should be accurately measured and recorded. From this data, a smooth height/diameter curve may be drawn in the field itself. Then the sample tree may be selected to cover the full range of diameters.

18. Measurement of Sample Trees: Standard measurements i.e. volume of standard timber, stem timber, stem small wood, crown length, bark thickness, sapwood percent in stem, etc. are taken and recorded. Average length of green crown and crown width are also measured and recorded. Data regarding age, mean height, mean girth or diameter, number of stems, basal areas and volumes per unit area are also collected and recorded. If the species has annual rings, the age of sample trees is also determined and recorded.

19. Measurement of Thinnings: During thinning if less than 12 trees are removed, all the trees will be measured. But if more than 12 trees are removed, only 8 or more trees may be selected and measured.

20. Re-measurement of the plots: Re-measurement of the sample plot will have to be done at intervals - once in 5 years or 10 years. This interval will coincide with the prescribed thinning cycle. Crown classes should be reassessed. Trees which show excessive or very low increment should be checked up. Missing trees should be taken as thinned and their last recorded measurements accepted. The cross marks and painting should be re-done. Boundary trenches and pillars should be repaired. The sides and diagonals of the plot should be re-measured and checked.

21. Field Records: The following records should be maintained:

i) Situation Map: A map on 1:25000 R.F. is prepared showing the situation of the plot with reference to the natural features, road, foot paths, or other prominent places along with the main topographical features and compartment boundaries. The diagram of the plot is inserted in this map recording the dimensions of the plot. A photograph of a typical portion of the plot is also taken and the camera position and direction of view should be permanently marked on the ground.

ii) Plot chart: A detailed map which will show the position of trees will be prepared on a 1:250 R.F. scale.

iii) Description of Plot: The sample plot will be described in the standard form 2 which is self explanatory to give full information about area, situation, climate, type of forest, age, condition of over-wood, weed growth, grazing or fire incidence, etc.

iv) Diameter measurement of crop: The callipers should be checked for their correctness before measurements. For every tree, height of the cross mark and two diameters should be recorded. Main crop and subsidiary crops are recorded on separate forms.

v) Measurement of Sample Trees: Height is measured in metres, correct to first place of decimals and 2 diameters at right angles are measured at breast height, at mid height and at half the height above the breast height. Height of green branches all round and height of stump are also recorded.

vi) Classification of Diameters: Trees are classified into 2cm diameter classes.

PROBLEMS

1) What do you mean by a Sample plot? Explain how you would lay out a sample plot and collect data.

2) What is the difference between
   a) sample plot and tree increment plot?
   b) sample plot and preservation plot?

3) What are the kinds of sample plot?

CHAPTER XIII

YIELD TABLES

1. Introduction: Forest mensuration gives the volume of the crops at present and also helps in the forecast of future yields. We have already studied the methods of estimation of present growing stock. But we must also be able to predict the future growth. This can be done through a table which may give yield of stand on unit area basis for the greater part of its useful life. The yield of a forest depends upon several factors such as its structure, growth, density, the productive capacity of the site, etc. Let us have some basic knowledge of these aspects of forest crops.

2. Stand Structure: defines the distribution and representation of age and/or size classes of trees in a stand. This will keep on changing with passage of time in age. At any particular period of its life, it is the result of

i) growth habits of the species
ii) factors of locality and
iii) the management practices under which it was originated and developed.

The stand structure may be evenaged and unevenaged.

2.1 Evenaged stand: The even-aged stand will consist of trees of approximately the same age. The period required to regenerate a stand varies from 1 or 2 years to 20 to 30 years. This depends upon the system of management and species concerned. Hence in evenaged crops, difference in age upto 25% of the rotation age is allowed - if the stand is harvested at or after 100 years. Though the trees are nearly of the same age-class, there will be keen competition for light and moisture. This results in crown differentiation. Hence the vigorous trees occupy the dominant positions. Less-vigorous trees occupy the dominated positions. Those left behind are suppressed. Hence there is a wide range of diameters found at any particular age.

2.2 Unevenaged stand: In the unevenaged stand, the individual stems vary widely in age. The range of difference will be more than 20 years and in case of long rotation crops it will be more than 25% of the rotation age. When nearly all age gradations or age classes are present in a particular area, it is called selection Forest. In India, we have yet to study the structure of unevenaged forests.

2.3 Growth of stand: Stand structure changes year by year as a result of growth, death and cutting of trees. The growth of any stand parameter viz., height, diameter, volume or biomass follows a pattern of slow growth in the beginning, rapid at an early age and slows down in the later years.

3. Method of Determining Past Growth: This can be done only by repeated measurement of sample plots since measurement of the whole woods is not possible. The method of repeated measurements in permanent sample plots is better than laying out temporary sample plots. Care should be taken to see that the sample plots, are true representative of the stand.

4. Method of Predicting Future Growth of Stands: Future growth of stands can be predicted with the help of Yield Tables, prepared from the studies of growth in sample plots, systematically distributed over the entire area. But growth of stand depends upon the stand density and site quality. Let us have a knowledge of stand density and site quality.

5. Stand Density is the measure of the relative completeness of tree stocking, expressed as a decimal co-efficient, taking normal number of trees, basal area or volume as unity. In India, it is synonymous with crop density, density of stocking and stocking. But in America, stand density is different from stocking. But in India, we call it over stocked, full stocked or under stocked when crop density exceeds one or equals one or less than one respectively.

5.1 It has been defined that stand density is a " decimal co-efficient taking normal number of trees or basal area or volume as a unity". We must know what the normalcy is. The yardstick to measure the normalcy in respect of any of these items can be had from the Yield Tables. The Yield Table will give for a given age, or crop diameter, the number of trees, basal area and volume. But the figures will be available only for those species for which yield tables is available. Yield Tables have been prepared so far only for evenaged pure crops. But for mixed forests no Yield Tables are available. In such cases, measurement of density will be only ocular. It refers to the canopy density. In such cases density should be expressed in terms of basal area per hectare.

5.2 The growth and yield of forests can be predicted with the Yield Tables but we must know the stand density. The Yield Tables are generally prepared for fully stocked crops. Hence without knowing the density of the stand, our prediction will not be correct. Once we know the density of the stand, we can apply the correction factor to the Yield Table figures to obtain the future growth or yield of stand.

5.3 How to find out the density? The number of trees or basal area or volume per hectare actually found in the stand in question should be compared with similar figures given in the Yield Tables. For example, Teak in site quality II, thinned regularly to 'C' grade at 80 years of age should have a standard stem timber volume of $241.4m^3$/Ha. as per the Yield Tables. Hence the crop density of the following three different teak forests of 80 years age, thinned to 'C' grade regularly in site quality II will be as shown below:

Particulars of forests having vol./Ha.	Yield Table volume to serve as a standard of comparison.	Crop density	Description of crop density.
1	2	3	4
i) $265.5m^3$	$241.4m^3$	1.1	Overstocked
ii) $241.4m^3$	$241.4m^3$	1.0	Fullstocked
iii) $217.3m^3$	$241.4m^3$	0.9	Understocked

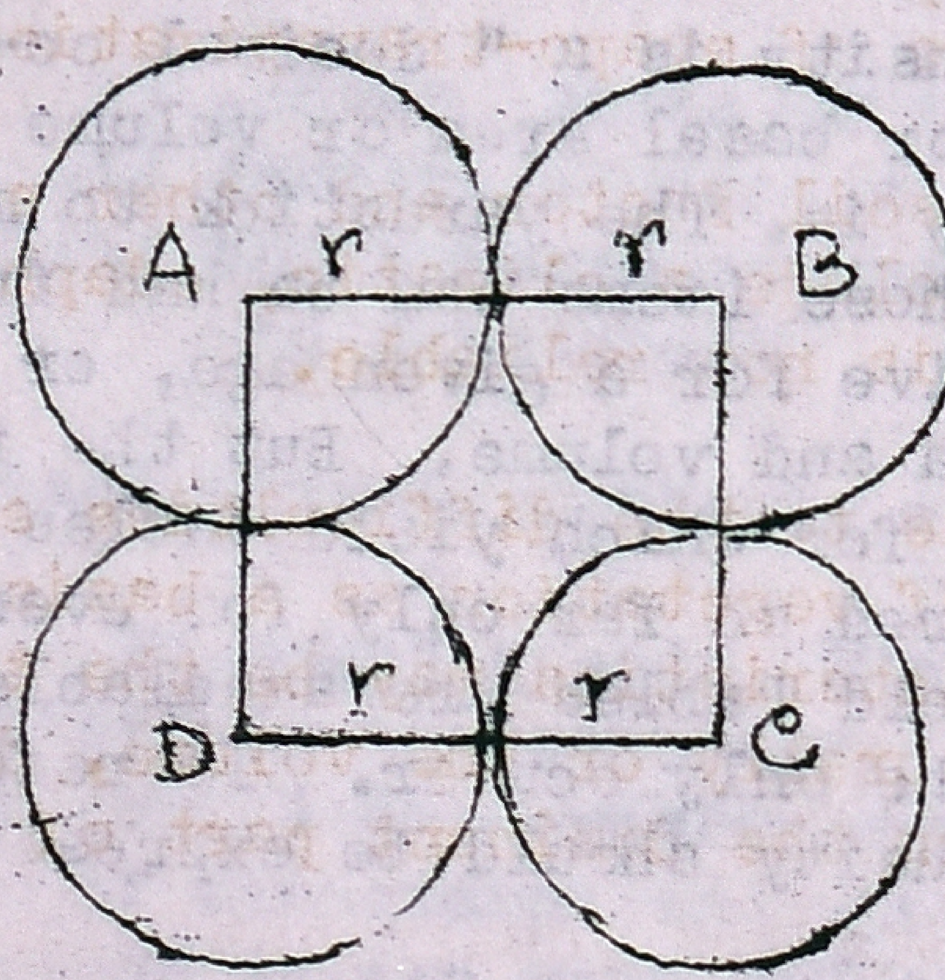
Thus the crop density of present stocking is worked out.

It is assumed that the same density will remain in future. The Yield Table figure given for any future age is multiplied by the crop density. This may give approximately the future growth of stands.

6. CANOPY DENSITY is the measure of relative completeness of canopy and is expressed as a decimal co-efficient taking closed canopy as unity. Hence canopy density describes only the relative completeness of the canopy. This has nothing to do with the number of trees, volume or basal area, etc. This may be helpful to give a rough indication of crop density of forests for which Yield Tables have not been prepared. The following are the classifications of canopy density in vogue.

i)	Closed:	When density is 1.0
ii)	Dense :	When density is between 0.75 and 1.0
iii)	Thin :	When density is between 0.5 and 0.75
iv)	Open :	When the density is under 0.5

Even in the pure evenaged crops, the canopy will not be closed completely. In square spacing the canopy closure is theoretically 0.7854 as shown in the figure.



Square spacing:

Area of square ABCD $= (2r)(2r) = 4r^2$

Area of crowns within ABCD $= 4\left(\frac{\pi r^2}{4}\right)$ i.e. πr^2

$$\frac{\text{Crown Area}}{\text{Round Area}} = \frac{\pi r^2}{4r^2}$$

$$\text{i.e. } \frac{\pi}{4}$$

$$= 0.7854$$

SITE QUALITY

7. Site is the complex of physical and biological factors of an area that determine what forest or other vegetations it may carry. Site quality is a measure of the relative productive capacity of a site for a particular species.

Every site gives a different growth response for different species. A sandy soil will yield good casuarina. A red soil area may give very good cashew. Hence a knowledge of this inter-relationship can help us in utilising particular area for the best growth for which it is suited.

Site quality can be evaluated by measurement of

i) Site factors or

ii) Vegetative characteristics.

7.1 SITE FACTORS: The climatic, edaphic and biotic factors influence the growth and development of vegetation of a locality. But it is very difficult to quantify the effects of these factors. The productivity based on these factors may be only very general. Hence it may not be reliable.

For example, PATTERSON proposed the following formula:

$$C.V.P.\ Index = \frac{Tr}{Ta} \times \frac{P \times G}{12} \times \frac{E}{100}$$

where CVP index = climate, vegetation, productivity index.
Tr & Ta = maximum and minimum temperature.
P = Precipitation in m.m.
G = Growing period in months
E = a measure of evapo-transpiration.

But this index does not include soil factor and other environmental factors. An ideal index should include a climatic, edaphic, topographic and biotic factors. Hence this is not reliable.

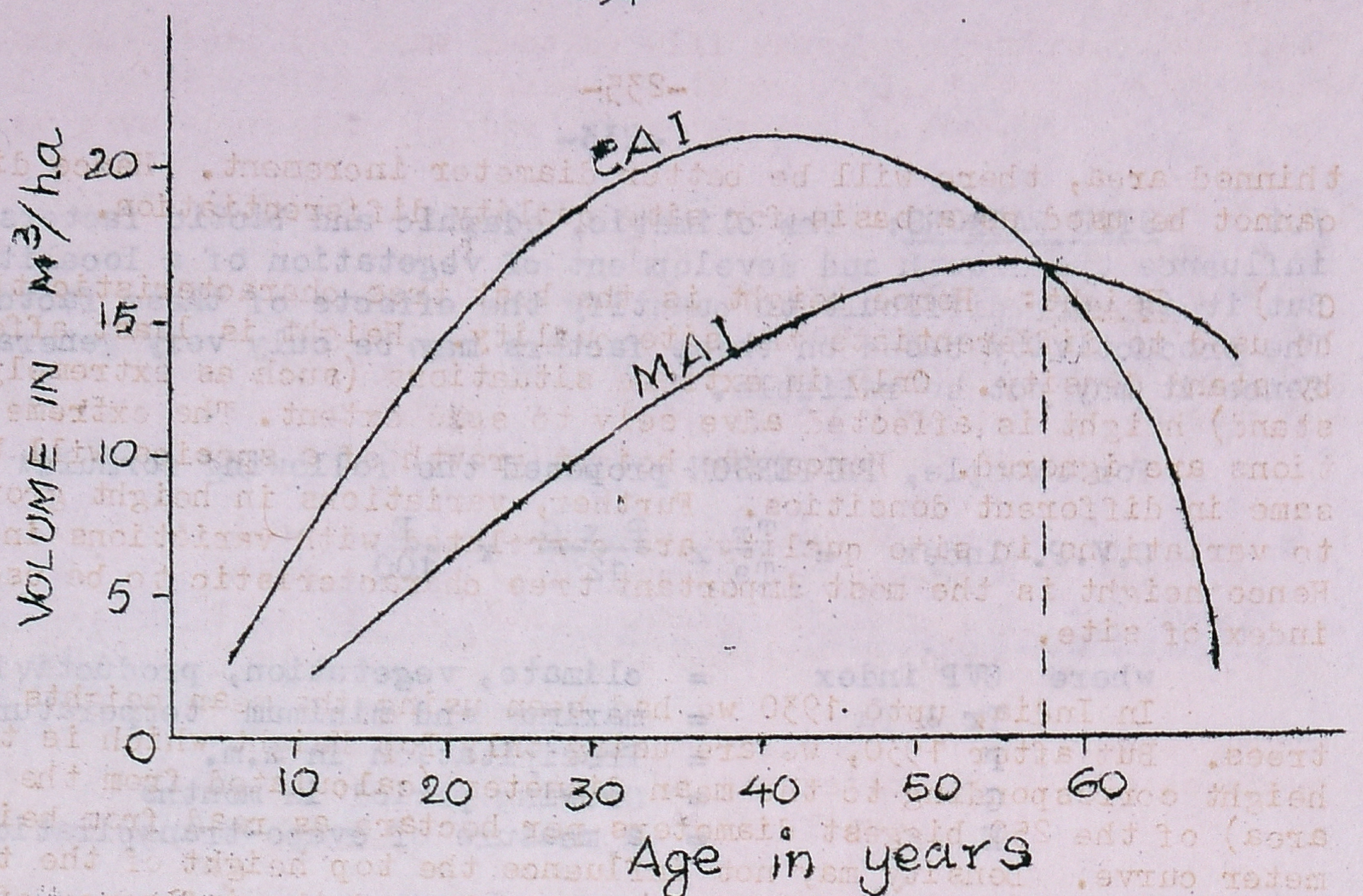
7.2 Vegetative Characteristics: Due to the difficulties explained, we must take only some characteristics of vegetation as a basis to differentiate site qualities. The characteristics may be the types of plants occuring in a particular site naturally or the volume, diameter, basal area or heights of trees which form the dominant part of the vegetation of the area.

i) Plant Indicators: In this case we have to search for some characteristic plants which may be correlated with site qualities. This method is based on the theory that certain species of lower vegetation i.e. herbs and shrubs are clear indicators of the suitability for a particular tree species or forest type. This method was used in the case of undisturbed forests of Finland and Canada. But this method cannot be used universally because

a) this can be applied for only to forests of simple composition
b) it requires considerable ecological knowledge
c) the lower vegetation which may provide plant indicators is easily affected by forest vegetation, density and biotic factors
d) the lower vegetation lies in the top few centimeters of the soil and so cannot indicate the conditions of the deeper layers of the soil which is important for the tree growth.

ii. Tree characteristics: Volume, basal area, diameter and height are the very important characteristics which will be based on the productivity of the site. For this, we must know as to what is the volume per unit area. But this is very cumbersome as it requires prior calculation of the volume.

iii. The Yield Class System of Classifying Growth Potential: The 1971 Forest Management Table (metric) of Forest Commission have used yield class systems for defining site qualities. This is described briefly below.



A) Volume: The volume increment pattern of an evenaged crop is depicted in the curve. We know that the volume increment of a stand increases after some years of growth and reaches the maximum after which the growth rate falls off. Look at the CAI curve, in the graph, which shows this fact. Similarly the MAI curve will show the average rate of increase in volume, from the time of planting to any period. The MAI curve reaches a maximum level where both the MAI and CAI curves meet. The maximum average rate of volume increment that is achieved by the particular species is shown by this culminating point. Theoretically this is the age at which the species should be felled and replanted.

This general pattern of growth is typical of all evenaged stands. But there will be differences of growth with the same species on different sites. The species that grows faster will have higher maximum MAI which will culminate earlier. Similarly there may be differences between the species. Maximum MAI of different species may be the same but may culminate at different ages. The important point here is that the maximum MAI is the maximum average rate of volume production which can be attained by a given species on a given site, irrespective of the time of culmination. It is this feature which is the basis of yield class system. Thus a stand of yield class 14 has a maximum MAI of about $14m^3/Ha$. But such classification can be used to categories of crops which have already reached their maximum MAI.

But there is a good relationship between top height and total volume of a stand. Hence the top height may be measured and this can be converted to total volume production. This total volume may be divided by the age which will give the MAI. Yields class obtained through top height and age of the stand is termed as " General Yield Class". Volume is likely to be affected not only by site quality but also by past treatment, density, etc.

B) DIAMETER: Next to volume, the most easily measured tree characteristic is the Diameter or Basal Area. But this is greatly affected by stand density. " Denser the stand, lesser the diameter" is the general trend of the stand (due to limited food, moisture and sunlight, shared by larger number of trees). In a more heavily

thinned area, there will be better diameter increment. Hence diameter cannot be used as a basis for site quality differentiation.

C) Height: Hence height is the best tree characteristic that can be used to differentiate the site quality. Height is least affected by stand density. Only in extreme situations (such as extremely dense stand) height is affected adversely to some extent. The extreme conditions are ignored. Hence the height growth of a species will be the same in different densities. Further, variations in height growth due to variations in site quality are correlated with variations in volume. Hence height is the most important tree characteristic to be used as index of site.

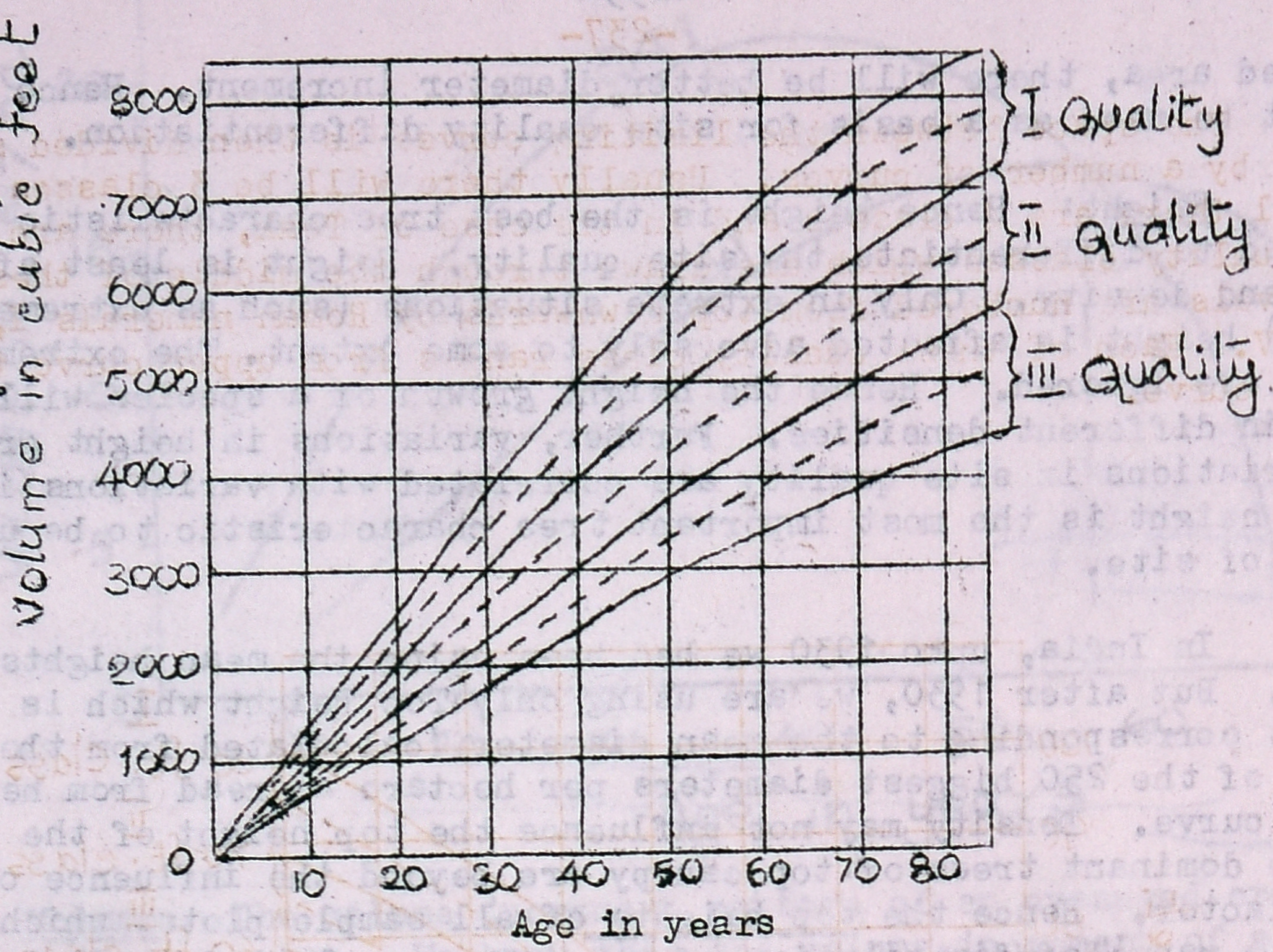
In India, upto 1930 we had been using the mean heights of all trees. But after 1930, we are using only Top Height which is the height corresponding to the mean diameter (calculated from the basal area) of the 250 biggest diameters per hectare as read from height/diameter curve. Density may not influence the top height of the trees, as the dominant trees of top canopy are beyond the influence of density factor. Hence the top heights of all sample plots, which cover a whole range of distribution of species, are plotted against the age.

8. DELIMITATION OF SITE CLASSES: Differentiation of the site classes can be done by one of the following methods:

8.1 BAUR'S OR THE STRIP VOLUME METHOD: Baur has used volume production per unit area for a given age as the yardstick for measuring site quality. Sample plots located in different site qualities are measured and their volumes are found out as at different ages. This data is graphed by plotting age against volume depicting age along x-axis and volume in y-axis on a suitable scale. Two curves are then drawn passing approximately through the highest and lowest points. Following is an example of measurements.

Sample Plot No.	Age in years	Volume in Cft/acre	S.P. NO.	Age in years	Volume in Cft per acre
1	15	1800	12	48	2900
2	17	1400	13	49	4700
3	18	1100	14	50	3500
4	21	1700	15	54	6400
5	27	3300	16	62	4700
6	29	2050	17	62	6200
7	34	3250	18	68	4450
8	35	2800	19	74	7800
9	35	4450	20	74	4000
10	46	4800	21	76	5500
11	47	4230	22	79	6300
			23	81	7200

From the above it can be seen that maximum volume is in sample plot Nos.1, 5, 9, 10, 15, 17, 19 and 23 and minimum volume is in sample plots 3, 6, 12, 14, 18 and 20.



The space between these limiting curves is then divided into as many strips of equal magnitudes as the number of quality classes. If we want 3 quality classes, the interspace between these two curves is divided into 3 strips of equal width as measured on any ordinate. The highest or first strip will represent first quality, middle strip will represent second quality and last strip will represent the third quality. Hence a mean curve through each strip may be drawn. This will be the mean volume curve for the particular quality. The volume column in the yield table can be prepared by taking readings from this mean curve.

Similarly particulars with regard to mean height, crop height, top height, mean diameter, total basal area, total number of trees, stem timber volume, etc. for a given age and for a particular site quality can be obtained from graphs drawn based on data collected from sample plots falling in that particular quality class.

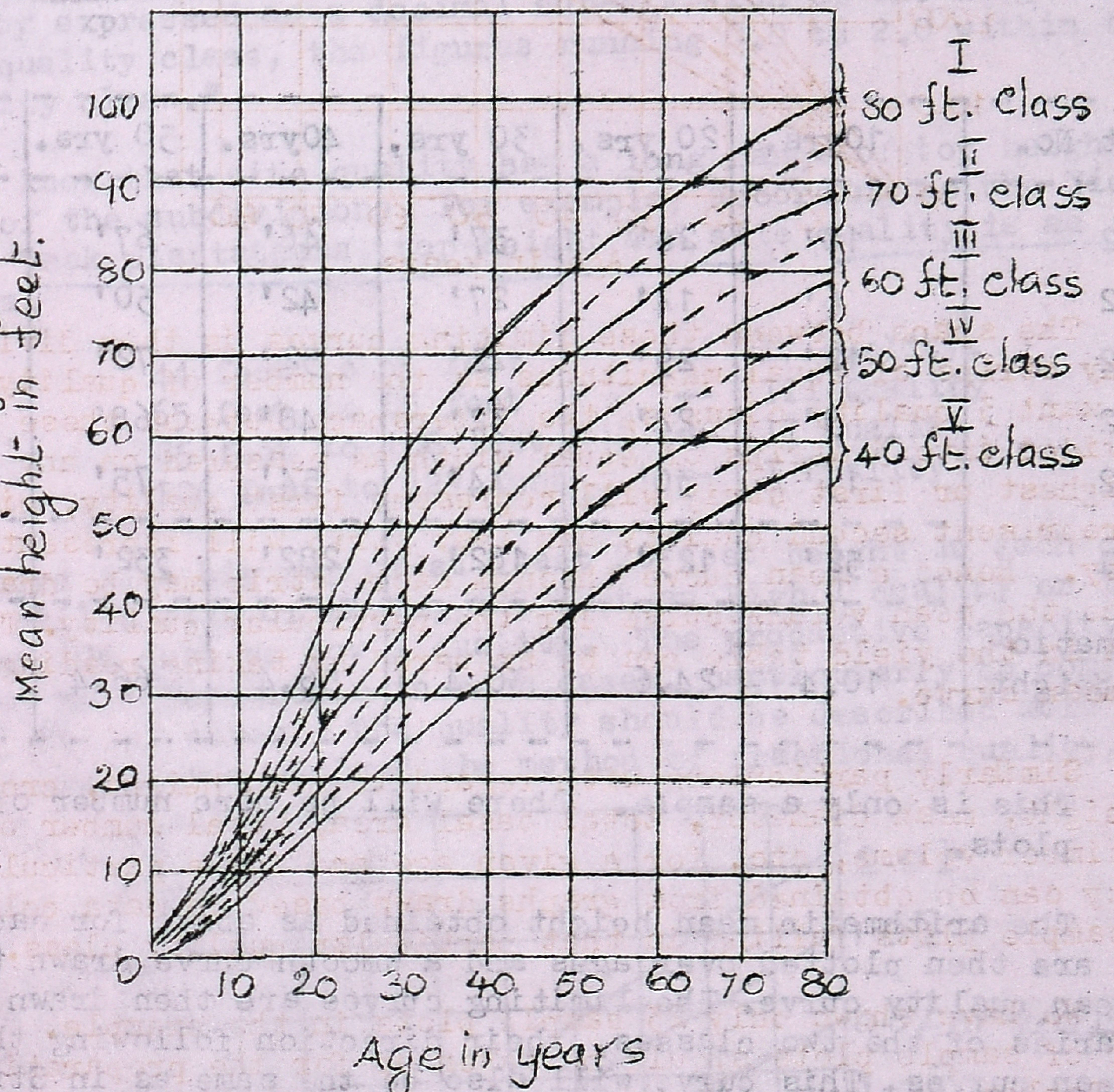
We have shown only 23 sample plots in the example. But more number of sample plots should be taken up for the preparation of Yield Tables.

8.2 STRIP HEIGHT METHOD: This is based on Baur's method. Instead of volume, Top height is used. In this case top height is taken as the average height of dominant trees. Height is not influenced by density, etc. and is easily measurable. Within the height, the height of dominant trees is more reliable than the height of dominated trees or suppressed trees. Hence, Top height or the average height of dominant trees has been accepted as the standard device for measuring site quality. This was suggested by SCHLICH, where height is used instead of volume. Procedure is the same.

Limiting curves are drawn. The number of qualities to be differentiated is decided keeping in view

a) the difference between limiting curves
b) practical limits of accuracy in height determination
c) closeness of management foreseen.

The space between the limiting curves is then divided symmetrically by a number of curves. Usually there will be 3 classes. In case of sal there are 4 classes and in the case of Teak, there are 5 classes. The quality classes which are drawn through the middle of these class intervals are numbered from top downwards by Roman numerals I, II, III and IV. Each of these quality class ranges from upper curve to the lower curve.



8.3 BRITISH FORESTRY COMMISSION (BFC) METHOD: BFC rejected the Baur's principle since the trend of the curves was determined by the limiting curves based on very few points of greatest and least growth. Their method is described below:

Sample plots are selected on all types of locality and of ages well spread over the area. After the necessary thinning, in each plot over 50 years age, 3 sample trees, having approximately the mean height of the crop, are selected and subjected to stem analysis and a mean height curve prepared. They fix 50 years as a suitable age in the case of coniferous woods as the quality indicator.

Mean height curves for each plot throughout their life are prepared. All such curves are brought in a single sheet and the range of height at 50 years is observed and divided into 10 feet

divisions representing quality classes. The number of quality classes for each species depends upon the range of height at 50 years. For example, if the range of height in 50 years is 40 to 80 feet there can be 5 classes. If it ranges from 50 to 70 feet, there will be only 3 classes.

On the basis of their heights at 50 years, the plots of this age and over are allotted to their qualities. Their average mean heights at different ages are calculated (by dividing the total mean height at different ages by the total number of plots in that class).

Example:

Quality III

Plot No.	10yrs.	20 yrs.	30 yrs.	40yrs.	50 yrs.	60 yrs.
342	10'	26'	37'	46'	67'	
352	6'	14'	27'	42'	50'	
362	12'	29'	42'	52'	72'	85'
372	9'	24'	32'	48'	68'	80'
382	15'	30'	44'	54'	75'	90'
Total	52'	123'	182'	282'	332'	235'
Arithmatic Mean Height	10.4	24.6	36.4	56.4	66.4	78.3

Note: This is only a sample. There will be more number of sample plots.

The arithmatic mean height obtained as above for each quality class are then plotted over ages and a smooth curve drawn to obtain the mean quality curve. The limiting curves are then drawn at the boundaries of the two classes, their direction following the trend of the mean curves. This curve will also be the same as in Strip-Height method.

Plots less than 50 years old are now allotted to their respective quality classes by the position given to them by their mean height or thin curve.

8.4 F.R.I. METHOD: This method is a compromise between the strip height method and British Forestry Commission (BFC) method. The procedure, as described in the Silviculture Research Code is given below:

The top heights of all plots are plotted on squared paper against their top ages and the points corresponding to the successive measurements of each plot are joined by straight lines. This scatter diagram is then divided into 4 or 5 arbitrary strips from top to bottom. The points within each strip are plotted separately on squared paper and through each strip, a smooth curve is drawn following the trend of the lines joining points for successive measurements of the

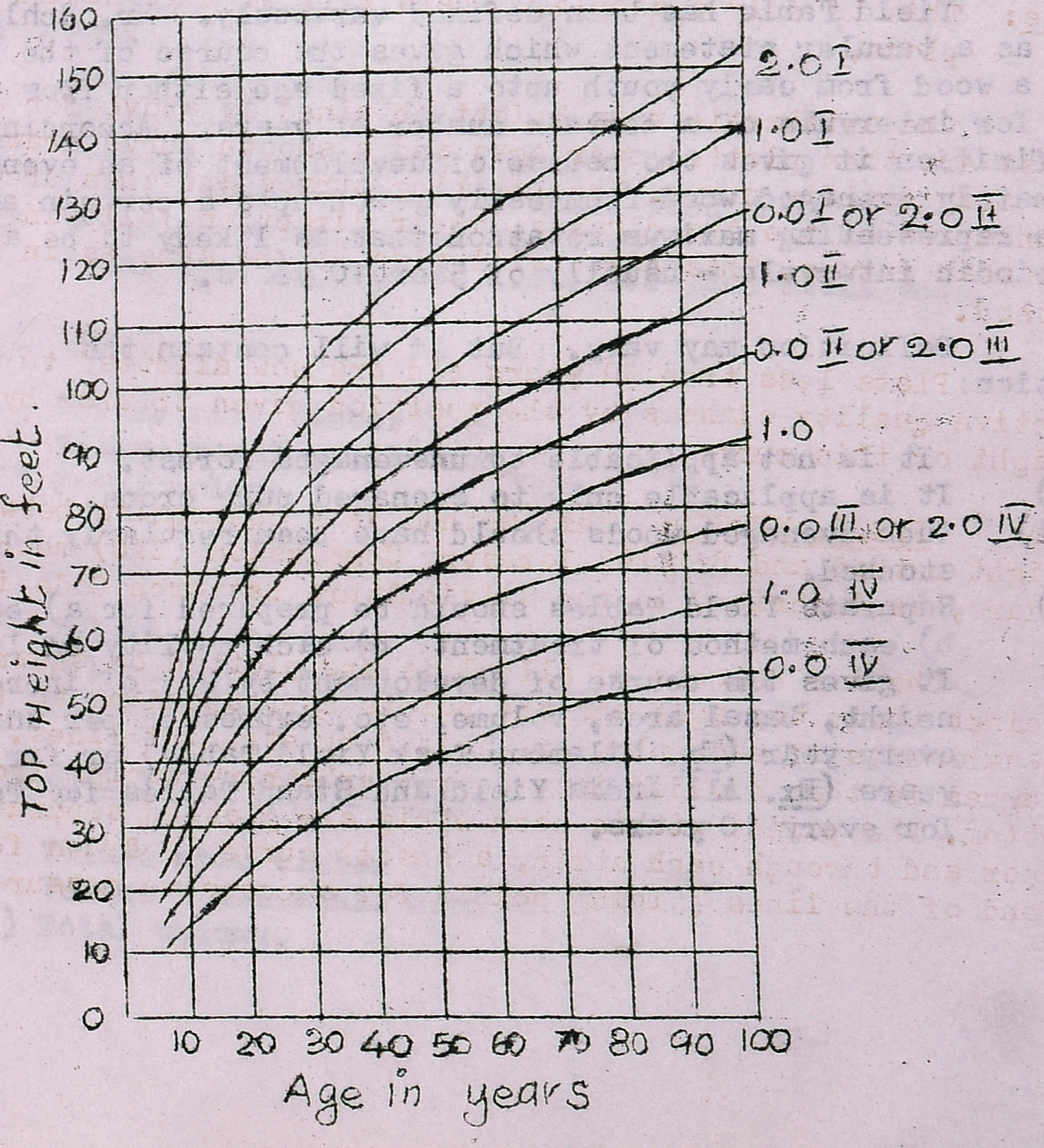
same plots. The curves thus obtained are transferred to a separate squared paper and mutually harmonized. These curves are used as guides to determine the trend of the limiting and mean curves of the site qualities. The age of reference for the site quality classes, the height intervals at that age and the number of site qualities are determined by examining the data in the scatter diagram. The curves for the limiting and mean values are then drawn through these fixed points at the age of reference, in conformity with the guiding curves. The limiting curves for the site qualities are then superimposed on the scatter diagram.

9. FRACTIONAL QUALITY: Fractional quality is defined as " the site quality expressed as a decimal sub-division of the height range of half a quality class, the figures running 0.0 to 2.0 within the whole quality class."

You know that site quality has a long range of top heights between each of the subdivisions. For example, according to the Yield Tables for Teak plantations, top height and site quality is as follows at 60 years.

44 feet to 65 feet	--	IV Quality.
65 feet to 85 feet	--	III Quality
85 feet to 106 feet	--	II Quality
106 feet to 127 feet	--	I Quality

There is a big gap of at least 20 feet height in each quality. We cannot call a site of having 125 feet as High I quality or the site having 106 feet as low I quality. The productive capacity cannot be measured by a Researcher in such cases, particularly to compare a site with that of other. The quality should be described more precisely. Hence Laurie evolved the method of fractional quality. He



pointed out that each quality class has a mean curve, i.e. upper curve and lower curve. Thus the lower limiting curve of one quality class will be upper limiting curve of the quality class next below. The mean is a point equidistant from upper and lower curves.

Hence if the lower limiting curve is signified as 0.0, the upper limiting curve will be 2.0 and the mean curve will be 1.0. The range of variation in any quality class can be expressed as a fraction of half of that quality class which ranges from 0.0 to 1.0 or 1.0 to 2.0.

Eg. A teak plantation of 60 years has a top height of 75 feet. This falls on the mean curve of III quality. Hence it can be said to be 1.0 III.

If the top height is 65 feet, it falls on the lower limiting curve of that locality. Hence, it can be called as 0.0 III or 2.0 IV quality.

If the top height is 69 feet it is clear that it is between 0.0 III and 1.0 III. This range is covered by 10 feet. Therefore an increase of 4' above 65' will be 4/10 of 1 (i.e. half the quality class). Hence it can be described on 0.4 of III quality.

A teak stand having Top height of 80' at 60 years will be of 1.5 III.

Hence a study of fractional quality class will be much helpful in predicting more accurate growth and yield of the stand.

10. YIELD TABLE :- Definition: Yield Table is a tabular statement which summarises per unit area basis all the essential data, relating to the development of a fully-stocked and regularly thinned even-aged crop at periodic intervals covering the greater part of its useful life.

Yield Table has been defined variously. Mr. Schlich has defined it as a tabular statement which gives the course of the development of a wood from early youth upto a fixed age either from year to year or for intervals of a certain number of years. According to some other definition it gives the course of development of an evenaged or approximately evenaged wood from early youth upto a certain age - generally age representing maximum rotation that is likely to be adopted at periodic intervals - usually of 5 or 10 years.

Definition may vary. But it will contain the following information:

i) It is not applicable to unevenaged forest.
ii) It is applicable only to evenaged pure crops.
iii) Such evenaged woods should have been regularly thinned and full stocked.
iv) Separate Yield Tables should be prepared for a) each species b) each method of treatment c) each quality of locality.
v) It gives the course of development by way of increment in height, basal area, volume, etc. expressed per unit area for every year (Ex. Nilambur Teak Yield Table) or for every 5 years (Ex. All India Yield and Stand Tables for Teak 1957) or for every 10 years.

11. VOLUME TABLE AND YIELD TABLES: Volume Table gives the volume of an average tree by diameter and/or height classes. But Yield Tables give different parameters of a crop such as number of trees, crop height, crop diameter, crop basal area, volume of standing crop, volume removed in thinnings, MAI, CAI, etc. Thus it gives all quantitative information regarding development of a crop.

12. OBJECTS OF YIELD TABLES: Yield Tables can be used for the following purposes:

i) Determination of the volume of woods at a given age.

ii) Determination of the increment of woods during a given period.

iii) Determination of the quality of a locality.

iv) Forecasting the yield of forests.

v) Choice of a most profitable species for a given locality and best method of treatment and rotation to be adopted for the species so chosen.

vi) Determination of the value of the soil, growing stock or both in a given locality.

13. CONTENTS OF THE YIELD TABLE: The contents of an Yield Table should meet the above requirements. The contents will change depending upon the circumstance of data collection or the objects with which they have been prepared. Most of the Yield Tables of India will give the following information by site qualities per unit area basis at interval of 5 or 10 years for the greater part of the useful life of the crop.

i) MAIN CROP:

i) Average diameter
ii) Average height
iii) Total basal area
iv) Number of trees
v) Stem timber form factor
vi) Standing volume stem timber
vii) Total (stem and branch) small wood form factor
viii) Standing volume-total small wood
ix) Total standing volume i.e., Stem and small wood.

ii) THINNING:

x) Volume stem timber
xi) Volume total small wood
xii) Total volume

iii) FINAL YIELD:

xiii) Volume stem timber
xiv) Volume Total small wood
xv) Total volume.

iv) ACCUMULATED YIELD OF THINNING:

xvi) Volume stem timber
xvii) Volume total small wood
xviii) Total volume.

v) TOTAL YIELD

xix) Volume stem timber
xx) Volume total smallwood
xxi) Total volume.

vi) MEAN ANNUAL INCREMENT

xxii) Volume stem timber
xxiii) Total volume

vii) CURRENT ANNUAL INCREMENT

xxiv) Volume stem timber
xxv) Total volume.

In addition to the above information Yield Tables give the following informations:

xxvi) Top height by site quality and age
xxvii) Spacement Table
a) by age and site quality
b) by crop diameter and site qualities.
xxviii) Number of trees per unit area by crop diameter and site qualities.
xxix) Normal growing stock of stem timber volume for 40 Ha. under different rotations, in case more than one rotation is in vogue.
xxx) Stand Table: " It is a table showing the distribution of stems by diameter classes for each of a series of crop diameters". It is a common practice in India to give the stand table along with the Yield Table. We shall study about stand table separately, in the next Chapter.

14. KINDS OF YIELD TABLES:

14.1 i) Local Yield Tables: If the data for the preparation of Yield tables have been collected from a restricted area (Ex. within the limits of a district) it can be called as Local Yield Table. Yield Tables for Nilambur Teak (1921) is an example. It is better if the yield tables are prepared for each thinning regime practised in that particular area.

ii) General Yield Tables: If the data had been collected from the entire habitat of the species within the country (Ex.) Yield Tables for Plantation Teak (1957) compiled by the F.R.I., Dehra Dun - it can be called as General Yield Tables.

14.2 It is further classified on the basis of number of grade of thinning used.

i) SINGLE YIELD TABLE: It is an Yield Table in which parameters have been given only for one grade of thinning which is usually 'C' grade.

ii) Multiple Yield Table: These are Yield Tables in which data are given for different grades of thinning. In India, multiple yield tables have been prepared for Cedrus deodara only.

14.3 Yield Tables are also classified on the basis of volume or value.

i) Volume Yield Tables: It is an Yield Table which expresses out-turn in terms of volumes.

ii) Money Yield Table: It is an Yield Table constructed from volume yield table in which out-turn is expressed in terms of money instead of volume.

15. PREPARATION OF YIELD TABLES:

Author's Note: The preparation of Yield Tables has not been included in the syllabus. However, the method of preparation is given below very briefly, as a guidance for the interested trainees.

Yield Tables will be prepared as follows:

i) Construct the Top height/Top age curve, by site quality, by any of the methods studied under para 8.

ii) Depending upon the position of sample plots in the curves, assign them to a particular quality class. Hence some sample plots will be in first quality, some may be in II quality and likewise.

iii) If the successive measurements of a particular sample plot lie in both qualities, find out the majority of measurements. If the majority of measurements lie in II quality (some measurements may lie in I quality) assign it to 2nd quality.

iv) This sample plot may also be allotted to the particular quality class based on the latest measurements. Suppose the measurements in 10th, 15th, 20th, and 25th year lie in II quality, and the measurements of 30th, 35th, 40th, 45th and 50th year lie in I quality, this plot may be allotted in I quality. Generally this is preferred to iii.

v) Take the figures of crop age and crop basal area per Ha. for each quality class by decade or half decade age classes (5 years). Compute their averages. Plot the average values of basal area against the corresponding average values of crop age. Draw a smooth curve for each quality. Take the reading of crop basal area for different crop age and tabulate. If there is much difference between the readings and actual measurements, the standard deviation and co-efficient of variations are computed and curved against crop ages. Measurements in which the difference exceeds twice the standard deviations may be rejected. Then the curve may be drawn.

vi) Similarly for each quality class, the main crop data of acceptable measurements should be grouped by decade or half decade age classes and the averages of the following data are computed.

a) Basal area per hectare.
b) Number of trees per hectare.
c) Average crop diameter
d) Average crop height.
e) Stem timber and stem small wood volume per Ha.
f) Stem Timber and Stem small wood form factor.
g) Top age and Top height.

vii) The average of each age class may be plotted against average crop age and smooth curves may be drawn for each quality. Necessary adjustments may be done between mutually related curves so that,

a) Number of trees per Ha x Average Basal area = Basal area per Ha. and

b) Basal area per Ha x Crop height x Form factor = Volume per Ha.

viii) The values against the decades or half decades of age are read from these curves and tabulated. The top age and top height values read from top age/crop age and Top height/Crop height curves are interpolated on the Top height/Top age curves (already drawn) to determine fractional qualities at each decade or half decade.

ix) The values tabulated from the remaining curves are plotted against their respective fractional qualities and smooth curves are drawn for each decade or half decade of crop age. The mutually related curves are cross-checked and adjusted. The values are read against each mean site quality and also against each limiting site quality and tabulated.

x) These values are plotted against crop age and smooth curves are drawn for mean and limiting site qualities and the mutually related curves are cross-checked and adjusted again. The values are read from these finally adjusted curves and tabulated.

APPLICATION AND USES OF YIELD TABLES

16. General uses: Yield Tables serve as an important tool in Forest Management and they are useful in solving the various problems that arise in forestry. Before using the Yield Tables we must know the age of the crop and its density. Age can be found out as discussed already. Density of crop can be found out by instruments like wedge prism and compare it with the basal areas given in the Yield Tables for the age and quality of the stand.

As Yield Tables contain lot of information it can be put to many uses in the management of forests or silvicultural practices. Some important uses are described below:

1) Determination of site quality or fractional site quality.
2) Computation of the Growing Stock or total yield at the present age.
3) Prediction of future yields from existing crops
4) Determination of increment of stand.
5) Determination of Rotation.
6) Preparation of Stock map by site qualities.
7) As a guide to silvicultural thinnings.

Let us study how the Yield Tables can be applied to the above important uses.

16.1 Determination of Site Quality or Fractional Site Quality:

The age and top height is important to find the site quality. For routine works, the height of few dominant trees can serve the purpose. The site quality can be determined by referring to the curves or the table " Top height by site quality and age ". Hence to get site quality, the Tables can be used.

A specimen of Top height by site quality and age for Teak has been furnished below:

Site Quality → / Age in yrs. ↓	I			II			III			IV		
	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0
20	87	79	71	71	63	55	55	47	39	39	31	23
30	101	92	83	83	74	65	65	56	47	47	38	30
40	111	102	92	92	83	73	73	64	54	54	45	35
50	120	110	100	100	90	80	80	70	60	60	50	40
60	127	117	106	106	96	85	85	75	65	65	54	44
70	134	123	112	112	101	91	91	80	69	69	58	47
80	140	129	118	118	106	95	95	84	73	73	61	50

Hence different ranges of top height is given for different site qualities for a particular age. Hence suppose the top height is 85 feet for a crop of 40 years, from the Table see the age and find out the column in which the top height falls. It lies in II quality. Similarly top height of 120 feet for a crop of 50 years lies in I quality.

Three top heights have been given in each of the columns for different qualities. The lowest forms the lowest limit of that quality. The upper line limit is of next lower quality. Hence this can be called to lie in the intermediate quality such as I/II or II/III or III/IV. For example a plantation of 50 years, having top height of 100 feet is lowest of I quality or highest of next lower quality i.e. II quality. This can be called as I/II. At age of 80 years a plantation of top height of 95' will be of high III quality whereas a crop of 118' will be of low I quality. If the height is 118', it is I/II. For fractional quality, a reference has to be made in the curves. Each Quality is having a mean curve. From the curve the fractional quality can be found out as described early.

16.2 <u>Computation of Total Yield or Growing Stock at the present age:</u>

The total volume of any crop of given age and quality can be read off from the age-volume curve, given in the Yield Tables - provided the density of the crop is normal i.e., the same as envisaged in the Yield Table. If the density varies, allowance has to be made for the variation in density.

<u>Method of Estimation:</u> Age of the stand should be found out from records or stump analysis. Top height is also found out. Now the quality class can be found out from the Yield Tables. Now the volume of the crop is read from the Table of the site quality of Yield Tables (the growing stock of the main crop or total yield) can be read. We know that the Yield Tables give data generally for 10 years or 5 years. Suppose the age falls between these period (say 52 or 57 years and so on), the total yield may be found by simple rule of proportion.

<u>Example:</u> The Yield Tables gives the volume of kail as $762.0 m^3$ at 60 years and $907.3 m^3$ at 70 years.

i) Find out the yield at 64 years.

Yield at 70 years	..	907.3
Yield at 60 years	..	762.0
Difference in 10 years	..	145.3
Mean Difference for 1 year	..	$14.53 m^3$
Difference for 4 years	..	= 4 x 14.53 = 58.12
Yield at 64 years	..	Yield at 60 years + Yield for 4 years. i.e. 762.0 + 58.12 i.e. <u>$820.12 m^3$</u>

ii) <u>Another method.</u>

Yield at 70 years	..	907.3
Yield at 60 years	..	762.0 (907.3 - 762.0)
Increment in 10 years	..	145.3
CAI for this period	..	$\frac{145.3}{10} \times 4$ = <u>58.12</u>
Yield at 64 years	..	(762.0) + 58.12) i.e. <u>$820.12 m^3$</u>

<u>Density:</u> The volume so assessed will be correct if the density of the crop and density as considered in Yield Tables is the same. We must check up this. Density can be ascertained with reference to volume, number of trees or the total basal area. Volume determination is difficult. The number of trees may not be a true indicator without the basal area. Hence, the basal area per unit area can be ascertained and compared with the basal area given in the Yield Tables. The ratio between the two can be worked out.

<u>Example:</u>

Basal area per ha. as given in the Yield Tables.	$160 m^2$
Actual basal area as found out in the field.	$120 m^2$

Then the density is .. $\frac{120}{160}$ i.e. <u>0.75</u> (stock factor)

The volume calculated already should be multiplied by this density. Thus the volume in the above example will be 820.12 x 0.75 = $615.09 m^2$.

16.3 Estimation of total yield or growing stock at some future age of a stand.

i) In fully stocked areas: The Yield Tables are supposed to have been prepared for fully stocked areas. Hence there will not be any variation in density. Suppose we want to predict the total yield at some future age - say 40 or 50 years, following will be the procedure.

Assess the present age and the corresponding site quality. Suppose the present age is 20 years and the area comes under II quality, then look up the appropriate columns of the Yield Tables for II quality against 40 or 50 years' age and read off the yield figures therefrom.

ii) In understocked or overstocked crops: This can be predicted on the assumption that present deviations from normal stocking (stocking as envisaged in the yield tables) will persist in future also. As already stated, the ratio between the actual crop basal area and the crop basal area as furnished in the Yield Tables for the particular age and site quality is first assessed. This ratio is called the Stocking factor, which will be less than one in case of understocked areas and more than one in the case of overstocked areas. The yield is read off from the Yield Tables as already stated and the Yield is multiplied by the stock factor to get the correct yield. This principle can be expressed in the form of a formula.

Let a be the present age of the forest.
Va the present volume as per yield table
va the actual volume of the stand at present.
Va + n the volume as per yield table after n years.

We have to find the yield at (a + n) years.

$$\frac{Va}{va} = \frac{Va + n}{va + n}$$

$$\text{Hence } (va + n)\, Va = va\, (Va + n)$$

$$va + n = va\, \frac{(Va + n)}{Va}$$

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16.4 Determination of Increment of Stand:

i) The yield tables give the CAI per unit area for every 5 or 10 years. If you want to find out the increment for a period of less than 10 years, it can be found out as follows:

Assess top height and age. Find out the site quality. Refer the Yield Tables and find out the CAI for 10 years. This can be multiplied by the area and stock factor.

Example: Find out the increment of *Acacia catechu* of II quality with density of 0.8 and area of 10 Ha. between 40 and 45 years age.

CAI between 40 and 50 years of kail from Yield Tables : 16.96m^3

Hence CAI for 10 Ha. .. .. 16.96 x 10 = 169.6 m^3
We want increment for 5 years.
Hence this will be 5 x 169.6 = 848.0m^3
This is for fully stocked areas. But our density is only 0.8. Hence increment for the given stand = 848.0 x 0.8 = 678.4m^3.

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ii) Increment can be found out as the difference between present and future volume, both being calculated as already explained.

However in both the cases, we assume that the increment is proportional to density. This may be possible only for short periods as in the case of stands whose low density may be due to presence of blanks.

16.5 Determination of Rotation: Rotation of the maximum volume production for the crops is the age at which the mean Annual Increment culminates. For this, the site quality is assessed. Then from the Yield Tables the age at which the M.A.I. culminates is obtained. This age can be found out even directly from the m.a.i./age curve. This age is the rotation. This does not include the establishment period. Hence the establishment period may be added to this age and rotation fixed.

Financial Rotation: But the rotation calculated in the above method gives little idea of financial return. But for larger sizes of timber we may get more value. Hence there is always a price increment for the larger sizes. Rotation should be fixed after considering this aspect also.

The age upto which a crop is allowed to grow is dictated by the market conditions and the average size which will fetch the most profitable return. Suppose we have demands for pole crop, the crop should be harvested much earlier than its maximum volume production. Hence the rotation which are financially profitable should be determined. For this we must prepare money yield table.

We must collect data for the average net value per unit volume of timber from trees of various sizes. These net value figures should be applied to the Yield Tables. We will get a set of money yield figures for the total crop at different ages. This, when divided by the age, will give the mean net value increment per unit area. These values may be plotted over age. The culmination point of this money net value curve, represents the age of rotation i.e. the age at which maximum net income can be got.

The market conditions will change from time to time and place to place. Hence rotation of maximum net income will have to be determined for each set of conditions.

16.6 PREPARATION OF STOCK MAP BY SITE QUALITIES: There will be lot of difference in the rate of growth of certain species like Teak. Hence a stock map by site quality may be prepared and kept, so that different treatments may be given to the Teak plantation to get the best rate of growth in each quality. For this purpose, the area may be divided into small plots of 1 sq. chain and heights of the dominant trees may be found out and recorded. The locality of the tree may also be marked in each square. The site quality may be determined from the Yield Table for the age and height for each square. The quality class boundaries are then drawn on the map. This has been dealt in Chapter XV.

16.7 AS A GUIDE FOR SILVICULTURAL THINNING:

i) Number of trees corresponding to a given age: The number of trees per unit area left after thinning at each age, as shown in the Yield Tables, provides a sufficiently reliable guide to silvicultural thinning. Hence the site quality of the crop to be thinned is first determined on the basis of the age of the crop and its top height. The trees existing before thinning are enumerated. The ratio of the enumeration to the number of trees given in the Yield Tables for the age and particular quality class is determined. The crop is then marked silviculturally and the number of stems per unit area to be left after thinning is so adjusted as to bear the same ratio to the Yield Table number after thinning. This ensures the same degree of abnormality in the number of trees left after thinning.

The above method is not of practical use. The Yield Tables are generally prepared on 5 years cycle. The thinning cycle of the forest crop may be greater than 5 years. Hence a rough correction will have to be applied. For this we must use " Final Crop Yield Tables ". The actual number of stems to be retained will be this figure multiplied by the ratio worked already.

Example: Thinning has to be done in 20th and 30th year for Teak. The plantation is of I quality. The number of stems per acre should be 102 and 61 at 20th and 30th year respectively. The existing stems in 20th year is 140. Then, the number of stems to be retained as after the thinning at 20th year will be $\frac{61 \times 140}{102}$ i.e. 84 trees.

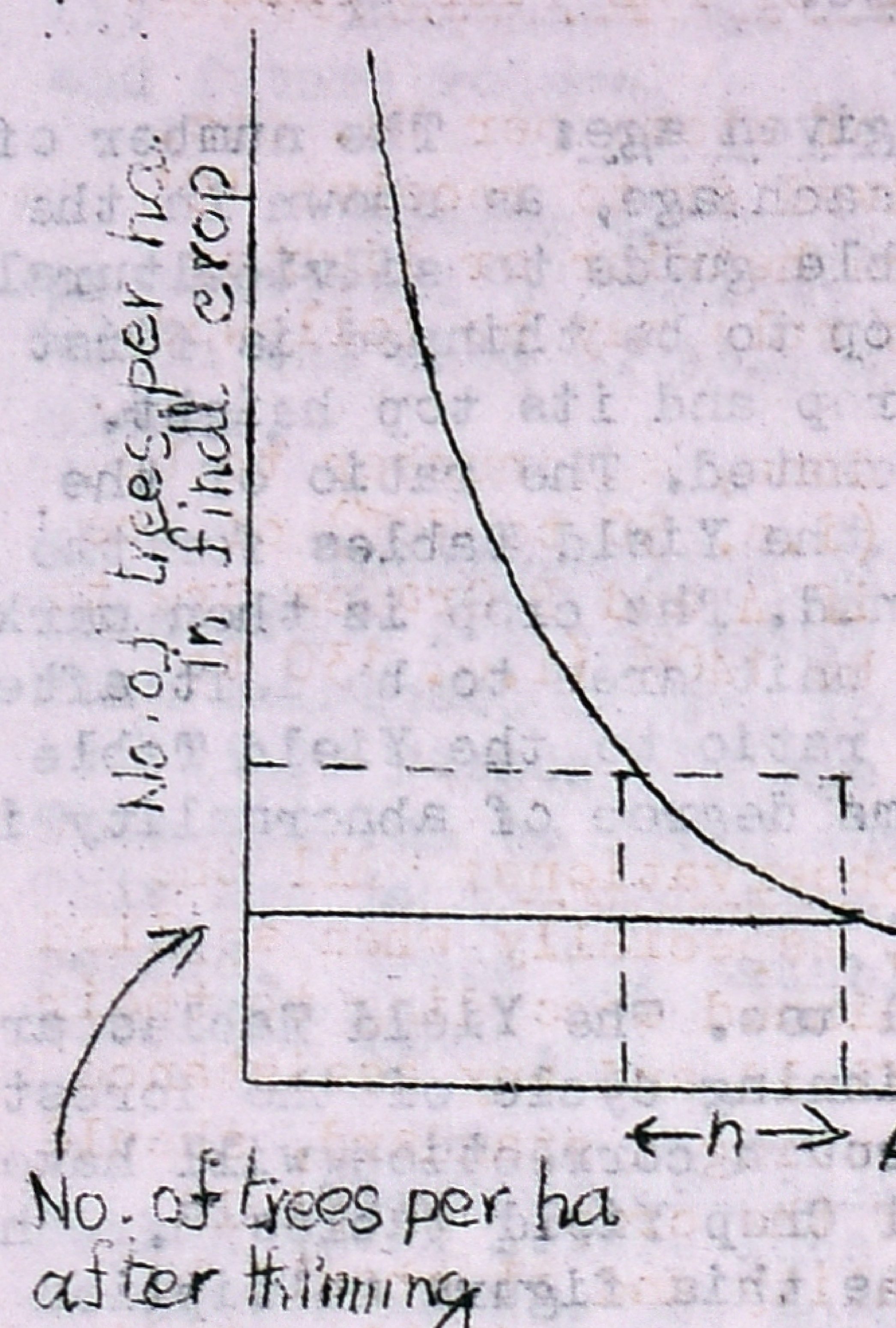
Thinning intensity may be higher in this method. But this can be justified on the grounds that the object of thinning is to anticipate congestion to set in and to remedy the situation, later.

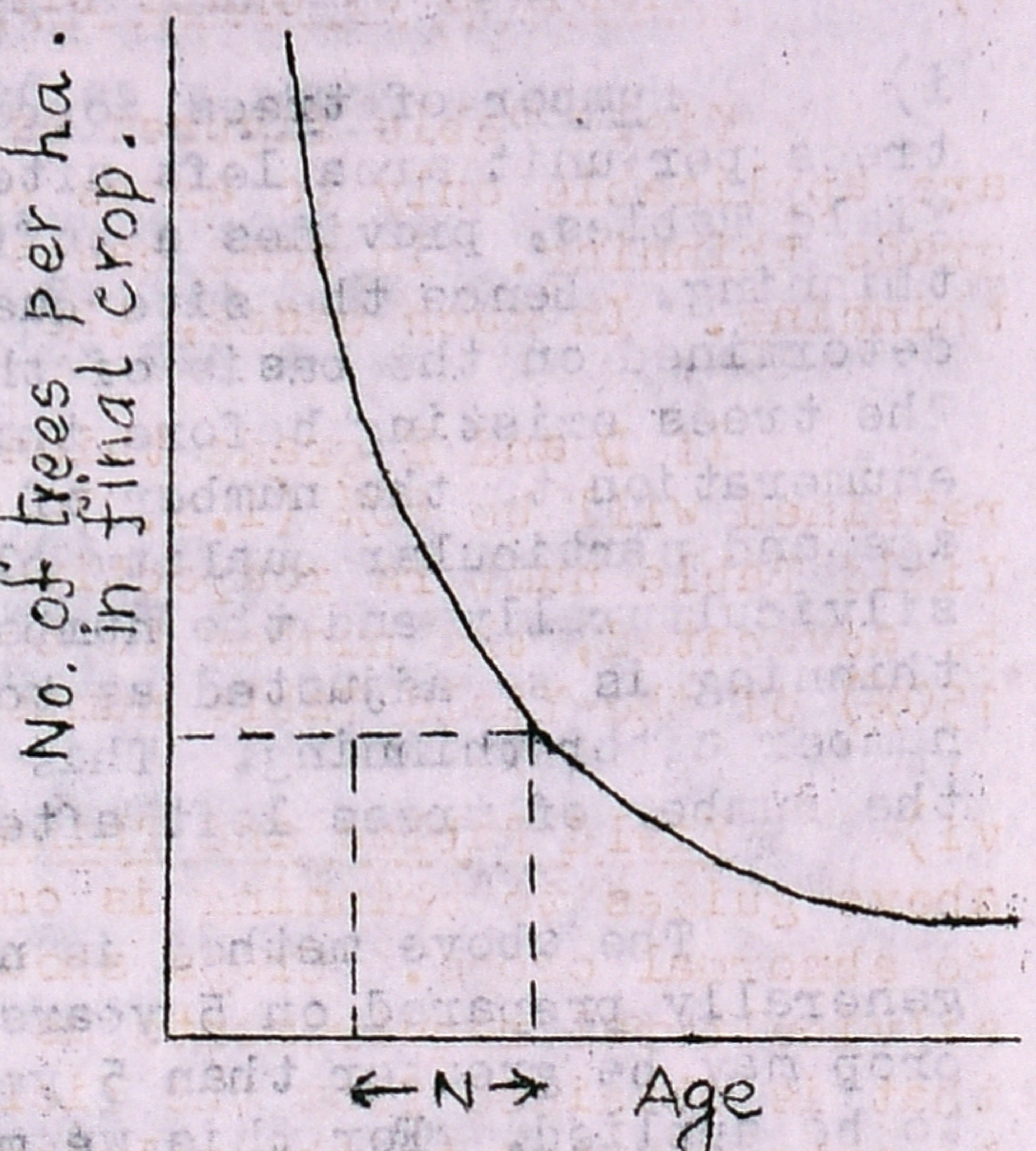
ii) By the use of the number of stems per unit area by site qualities curve:

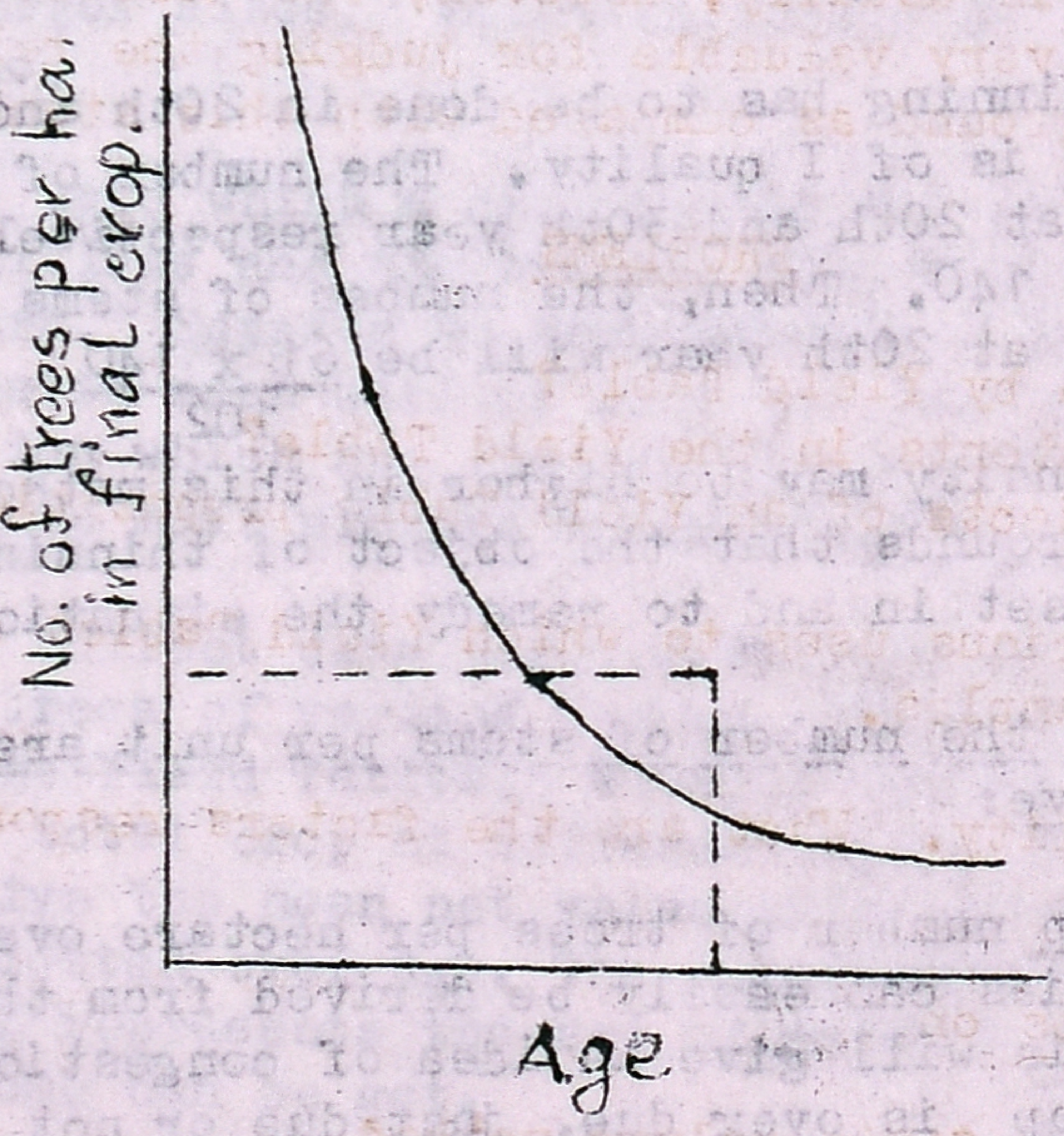
The final crop number of trees per hectare over age curve for different site qualities can easily be derived from the corresponding main crop curves. This will give an idea of congestion in a crop to decide whether the crop is over due, just due or not due for the thinning. For this, first of all, with reference to the top height and age, the fractional quality is found out. The number of trees per hectare is also found out.

The fractional quality curve has to be correctly interpolated with reference to the site quality curves in the graph. Then the actual number of trees per hectare is plotted against age. If this point falls on the interpolated curve, for fractional quality, the stand is just due for thinning. (Point A in the graph is the plotted point of number of trees per ha. and age). If the point H lies on the left of the curve, it is not due for thinning and the number of years at which it will become for thinning can be found out from X axis. If the point A lies on the right, the crop is over due for thinning.

If the thinning interval is n years and the crop is due for thinning, the number of stems to be removed is obtained by drawing a horizontal line from the point on the curve to distance representing n years. A perpendicular from this point to the curve will give the number of trees per ha. after thinning.







iii) <u>Number of trees corresponding to a given crop diameter</u>: The Yield Table gives the number of trees of main crop per ha. for a given crop diameter for the different site qualities - irrespective of age. The site quality of the area to be thinned is assessed. A tentative marking for silvicultural thinning is done, using the table of spacement (by crop diameter and site-qualities). Then the crop diameter of the remaining stems as well as the number of stems per Ha. so retained are found out. These numbers are then compared with the Yield Table figures for <u>the number of stems to be retained against the above crop diameter</u> for the particular fractional quality. Then marking is adjusted to get the number of stems retained to the Yield Table number found out as above.

iv) <u>Number of stems corresponding to a given Top height</u>: Differentiation into site qualities cannot be made in the case of young trees in which there would not be the crown differentiation. In such cases, the number of stems/crop height curves for the various quality classes can be made use of to decide on the number to be retained. In the case of Teak, such crown differentiation sets in only after the plants attain a top height of 12m.

v) <u>THINNINGS OF GRADE DIFFERENT FROM THAT OF THE YIELD TABLES:</u>

Yield Table figures as to the number of stems per Ha. etc. are applicable only to areas which have received or to receive 'C' grade thinning. In some cases, we may require heavier or lighter thinning. In such cases, the following thumb rule may be followed.

If D and E grade thinnings are to be done, the number to be retained will be 80% (i.e. 70 to 90%) or 60% (i.e. 50 to 70%) of the Yield Table numbers respectively. Similarly if A and B Grades are to be advocated, the number to be retained will be 140% (i.e. 130 to 150%) of the Yield Table number.

vi) <u>Yield Tables and Thinning: General observations:</u> All the above guides to thinning is only approximate, especially when applied to abnormal crops. Crops should always be thinned according to their silvicultural requirements as judged in the field and any assistance that is obtained from the Yield Tables, as setting a standard, should be subordinated to the silvicultural needs of the crop. No Yield Table represents a perfect standard of normality and it should be regarded as such. It is usually, however, the best available standard at the moment. It is very valuable for judging the relative condition of crops on the ground as compared with this standard.

PROBLEMS

1) What do you mean by Yield Table?
   What are the contents in the Yield Table?
   What are the objects of an Yield Table preparation?

2) What are the various uses to which Yield Tables can be put to? Explain with examples.

3) Define site quality. What are the factors responsible for site quality?

4) Write short notes on

   a) Baur's or the Strip volume method.
   b) Strip Height method.
   c) Fractional quality.
   d) Money Yield Table.
   e) Density of crop.

CHAPTER XIV

STAND TABLES

1) Definition: A stand table is a tabular statement showing the distribution of stems by diameter classes for each of the series of the crop diameters per unit area for various ages and quality classes. In India, it is usually treated as an auxillary to the Yield Tables and appended at the end of the Yield Tables.

2) CONTENTS: Stand Tables usually contain the following:

i) Tables showing the percentage of trees above a given diameter limit in crops of various diameters. Usually this is done in a combined manner for all qualities as it is found that the distribution of trees by diameter classes is largely independent of site quality and primarily a function of average diameter.

ii) Tables showing the number of trees per acre or hectare above a given diameter limit, for various site qualities, at successive age periods of 5 years interval.

iii) Tables showing in percentage of trees by 10cm diameter classes in crops of various diameters.

iv) Tables showing the percentage of total number of trees by 10cm diameter classes, for various partial crop diameters excluding trees below a certain limit.

v) Tables showing number of trees by 10cm diameter classes for 40 Ha. of normal forest under different rotations before the annual fellings.

A specimen copy of Stand Table is given separately by way of illustration.

3) OBJECTS: Stand Tables are very useful for the Forest management and it has been now accepted that Yield Tables is not complete without the stand tables. Stand Tables provide a ready means of determining approximately of the Yield Table number of trees for the various ages and site qualities according to their component diameter classes. Hence they are useful in

a) the valuation of forests on a financial basis

b) the preparation of money Yield Tables

c) application of commercial volume tables made for local standards of conversion to Yield Table Crop data.

4) COMPILATION: The standard method is by " Alignment chart " as described in page 201 to 206 of Silvicultural Research Code Vol.III. Briefly stated, the method consists of collecting necessary data from the various sample plots, graphing the data so gathered, harmonising the curves, and furnishing it in a tabular statement taken from the curves.

5) APPLICATION AND USES OF STAND TABLE: The particulars given in the Stand Tables represent statistical averages of data collected from various sample plots, located in normally stocked regular forests. Hence it can give a fairly accurate results only when it is applied to the normally stocked regular forests, of distribution of the various diameter classes in such crops and by virtue of this fact, the stand table can be put to the following important uses.

i) Determination of financial value of the crop
ii) Preparation of money yield tables.
iii) Estimation of volume Yield per hectare of converted timber of given size limits.

Let us see how it can be applied.

i) Determination of Financial Value of the Crop: This can be applied only to normally stocked regular crops.

Determine the crop diameter and quality class of the area. Then the pattern of stem distribution amongst the various diameter classes corresponding to the crop diameter and quality class is ascertained from the Stand Table. (This has been illustrated with example below). Then the volume of commercial timber available can be found out with the help of the Local Volume Tables - in each diameter class. Then the volume yield in each diameter class is converted into money yield by calculating the money value according to the prevailing price for timber of various size classes. The cost of exploitation may be determined in each case. Now we get the financial value of the crop.

EXTRACT OF STAND TABLE (MAIN CROP)(TAKEN FROM THE YIELD AND STAND TABLE FOR PLANTATION TEAK (1964) I.F.R. VOL.9 No.4)
Showing the percentage of Trees above given diameter limit in crops of various diameter

Diameter limit in inches	Average Crop Diameters in inches															
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	73	96	99.5	100												
2	21	67	94	99	100	100										
3	20	22	63	90	98	99	100	100								
4		3	21	59	87	96	99	99.5	100							
5		0.5	5.0	26	59	85	94	98	99	100	100					
6			1.0	6	30	60	81	92	96	98.5	99.5	100				
7				1.5	9	34	58	77	90	95	98	99	100	100		
8				0.5	2.5	12	34	56	74	88	94	99	99	99.5		
9					0.5	4.5	13	33	54	72	87	93	96	98.5	100	100

The above Table is used for the following i) to find out the distribution of trees into diameter classes for various crop diameters.

Example 1: If the average diameter of the crop is 5", the trees of various diameter classes are in the following ratio:

8" diameter class and above		..	0.5%
7" diameter class	(1.5 - 0.5)	..	1.0%
6" diameter class	(6 - 1.5)	..	4.5%
5" diameter class	(26 - 6)	..	20%
4" diameter class	(59 - 26)	..	33%
3" diameter class	(90 - 59)	..	31%
2" diameter class	(99 - 90)	..	9%
1" diameter class	(100 - 99)	..	1%
	Total	..	100%

Example 2: If the average diameter of crop is 8", the trees of various diameters class are in the following ratio:

9" diameter class and above		..	13%
9" diameter class	(34 - 13)	..	21%
7" diameter class	(58 - 34)	..	24%
6" diameter class	(81 - 58)	..	23%
5" diameter class	(94 - 81)	..	13%
4" diameter class	(99 - 94)	..	5%
3" diameter class	(100 - 99)	..	1%
	Total	..	100%

ii) To find out trees above a certain diameter for any crop diameter.

Example 1: If the average diameter of crop is 9", trees above diameter of 9" will form 33% of the crop.

Example 2: If the average diameter of crop is 12", trees above diameter of 9" will form 87 of the crop.

Example 3: If the average diameter of crop is 7", trees above diameter of 6" will form 60% of the crop.

iii) To find out trees between any certain diameters for any crop diameter.

Example 1: For a crop diameter of 12", the percentage of trees between 6" and 9" is 99.5 - 87 i.e. 12.5%.

Example 2: For a crop diameter of 10", the percentage of trees between 4" and 8" = 100 - 74 = 26%.

Example 3: For a crop diameter of 6", the percentage of trees between 4" and 8" will be (87 - 2.5) i.e. 84.5%.

EXTRACT OF STAND TABLE (MAIN CROP) GIVING THE PERCENTAGE OF TREES BY 4" DIAMETER CLASSES IN CROPS OF VARIOUS DIAMETERS

Diameter classes	Crop Diameter in inches													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Percentage													
0- 4"	100	97	76	41	13	4	1	1						
4 -8		3	24	58	84	84	65	43	26	12	6	1	1	
8-12				1	3	12	33	53	67	69	57	43	31	17
12-16							1	3	7	18	34	48	56	58
16-20										1	3	5	11	22
20-24												1	1	2
24-28														

Example 1: In a crop of 15" average diameter, the percentage of the total number of trees above 12" diameter will be 58 + 22 + 2 -- 82%.

2: In a crop of 12"diameter, the percentage of total number of trees between 16 to 20" will be 3%.

3: In a crop of 12" average diameter the percentage of the total number of trees above 8" diameter will be 57 + 34 + 3 =94%.

4: In a crop of 6" diameter, the percentage of total number of trees between 4" and 8" diameter will be 84%.

ii) PREPARATION OF MONEY YIELD TABLES: Money Yield Table is a table constructed from Volume Yield Table in which yield is expressed in terms of money instead of volume. Its main object is to determine the best financial rotation. The market will have fluctuations. The rates of sale of timber will vary according to the sizes. Hence volume yield table cannot be converted into money yield table. This is done with the help of

a) stand tables for the main and subsidiary crops distinguished by site qualities.

b) Assortment Tables showing the assortments available from trees of various diameter and height classes.

c) Money tables showing the relative value per cubic metres in monetary units obtainable from various assortments.

Money Yield Tables can be prepared as follows:

1) The volume per hectare for main crop and thinnings at different ages is obtained from the volume yield table.

2) The number of trees of different sizes is found out for various ages from the stand table.

3) A price-size gradient relationship is established between the crop age and its value in terms of money. Curves giving value/age or value/d.b.h., as per hectare basis, are known as price-size gradient.

4) With the help of this gradient, stand table data is converted in terms of money. Total value per hectare is found out by adding the values of all trees of different classes. These values are found out for main crop and thinnings.

5) The value of the crop per cubic metre at different ages is worked out for main crop and thinnings.

6) Finally money Yield Table data is tabulated in appropriate columns.

But Money Yield Tables will have to be revised frequently depending on the change of rates of timber in the market.

iii) ESTIMATION OF VOLUME YIELD PER HECTARE OF CONVERTED TIMBER OF GIVEN SIZE LIMITS:

When exploitation is done with specific lower or upper size limits, as in the case of extraction of Railway sleepers, electric transmission poles, etc., Yield Tables data will not be helpful to estimate the utilizable volume of timber of a given area. For this we want the help of Yield Tables, Stand Tables and Assortment Volume Tables. For using Assortment Table, we may require the height of each component inch-diameter class under a crop diameter class. This height can be read off from the height/diameter curve for any given diameter.

PROBLEMS

1) What is a Stand Table?
What are the contents of a Stand Table?

2) What are the uses of Stand Table?

3) Write short notes on Money Yield Tables.

CHAPTER XV

QUALITY CLASS MAPPING

1. Stock mapping is the mapping of the stock i.e. the growing stock of all the trees growing in a forest or part of it. This will give the distribution of different forest types or stand types and give description of distribution of different age classes and size classes, etc. Stock mapping is a must for the preparation of working plan which is the tool of forest management. Stock mapping consists of not only assessment of growing stock - but also assessment of productive capacity or site quality of different sites occuring in a forest area. Hence quality class mapping is the means, generally applied to assess the productive capacity of different sites of the forest area.

2. Site and Site Quality: Site is the complex of physical and biological factors of an area. Site quality is defined as a measure of productive capacity of a site for a particular species. We have already studied about the site, site quality, the factors responsible, assessment of site quality, etc. under " Yield Tables ".

3. Procedure:

i) Ascertain the age of the plantation.
ii) Determine the top height at various parts of the plantation.
iii) Locate these trees in a graphical map.
iv) Based on age and top height assess the site quality from the Yield Tables.
v) Thus quality class of different portions of the plantation is known.
vi) This can be mapped, quality classwar.

4. Equipments needed:

i) Yield Tables of the particular species.
ii) Large scale surveyed sketch of the plaantation, super-imposed on a graph paper.
iii) Chain and arrows.
iv) Prismatic compass or cross staff.
v) Tape
vi) Abney's level or Haga's Altimeter.
vii) Bill hook
viii) Tar or chalk
ix) Scale, pencil, rubber, etc.

5. Field work:

i) Parambulate the plantations.
ii) Fix up a convenient base line. Let this line extend from one end of the plantation to the other end of it.
iii) Cut strip lines on either side of the base line and at right angle to the base line.
iv) Plant pegs of 1m long along the strip line at every chain, starting from the base line.
v) Any obstructing under growth should be cleared.
vi) Now the plantation has been divided into one chain square plots.
vii) All the pegs planted will be in a line and the lines will be parallel to each other.

viii) Now select the tallest tree in each square plot and measure its height with the help of Abney's level or Haga Altimeter.

ix) Locate the position of the tallest tree in the graphed sketch.

x) Find out the quality class or fractional quality from the Yield Tables and note it in the respective square of the graph I, II, III, I/II, II/III, etc.

6. How to find out site quality: An extract of Yield Tables for Teak has been given below for 10 year intervals.

TOP HEIGHT BY SITE QUALITY & AGE

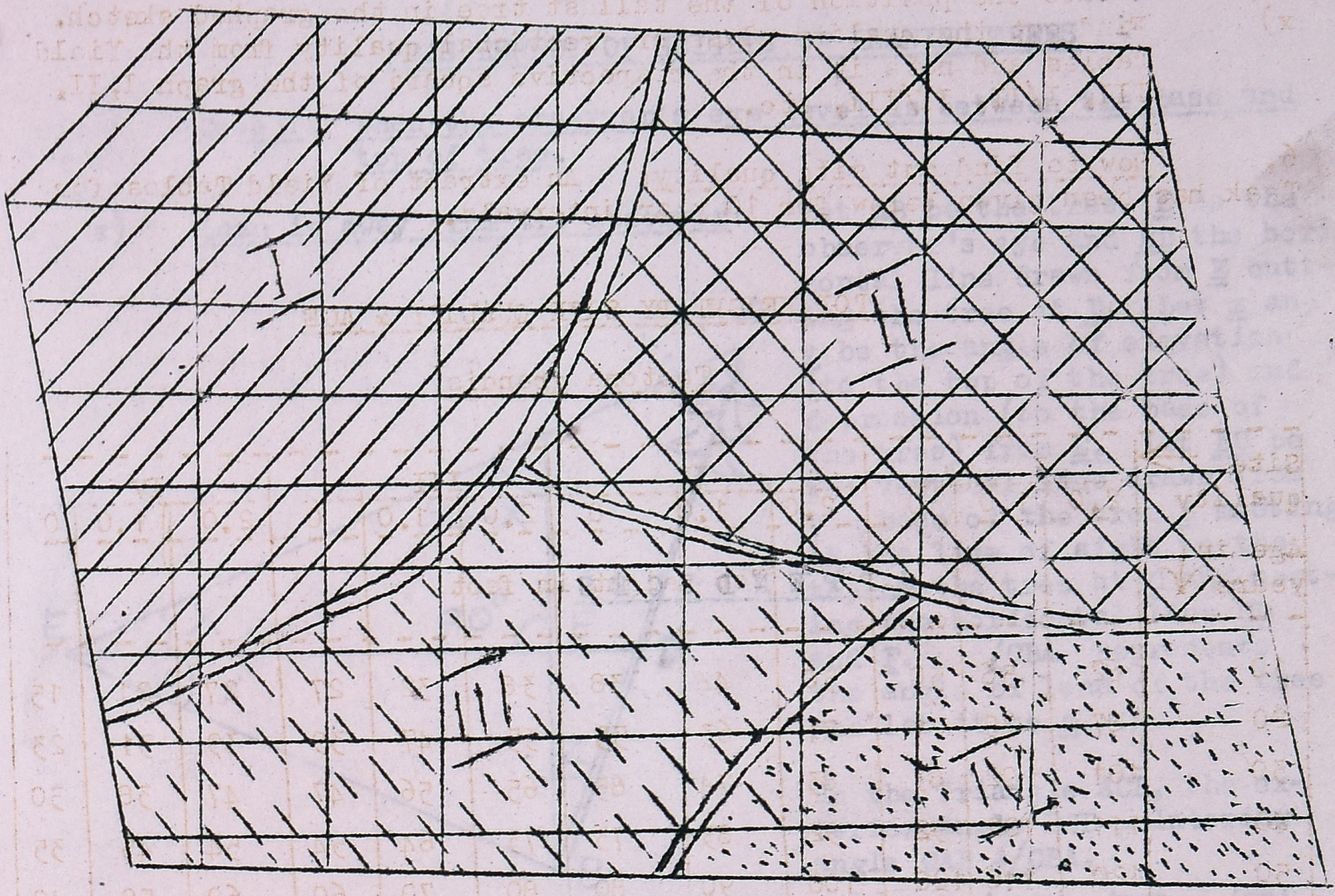
Tectona grandis

Site quality →	I			II			III			IV		
Age in years ↓	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0
	Top height in feet											
10	62	56	50	50	44	38	38	32	27	27	21	15
20	87	79	71	71	63	55	55	47	39	39	31	23
30	101	92	83	83	74	65	65	56	47	47	38	30
40	111	102	92	92	83	73	73	64	54	54	45	35
50	120	110	100	100	90	80	80	70	60	60	50	40
60	127	117	106	106	96	85	85	75	65	65	54	44

Example: Let the age be 30 years.
If Top height is 94 feet, it comes under 1.0 of I quality.
If Top height is 90', it is 0.0 of I quality.
If Top height is 83' it is I/II quality, as it is 0.0 of I and 2.0 of II quality.
If Top height is 75' it is 1.0 of 2nd quality.
If Top height is 50' it is 0.0 of III quality.

7. Mapping:

i) Connect the points i.e. the location of trees of equal quality class, so that the enclosure will have maximum number of same quality class. One or two squares of some other quality that lie in a big group of particular quality (Ex. Suppose the enclosure has 20 to 25 squares of I quality and 3 or 4 squares of II quality) they can be ignored.



ii) Each enclosure should be closed so that each of them will represent a particular site quality. Smooth curves should be drawn connecting the points.

iii) Each enclosure may be colour washed and the map should be indexed. The area falling under each quality may be computed.

8. <u>Research purposes</u>: For research works, top height will have to be assessed i.e. the mean height corresponding to the mean diameter (calculated from basal area) of the 250 biggest diameters per hectare for each plot as read from the height-diameter curve.

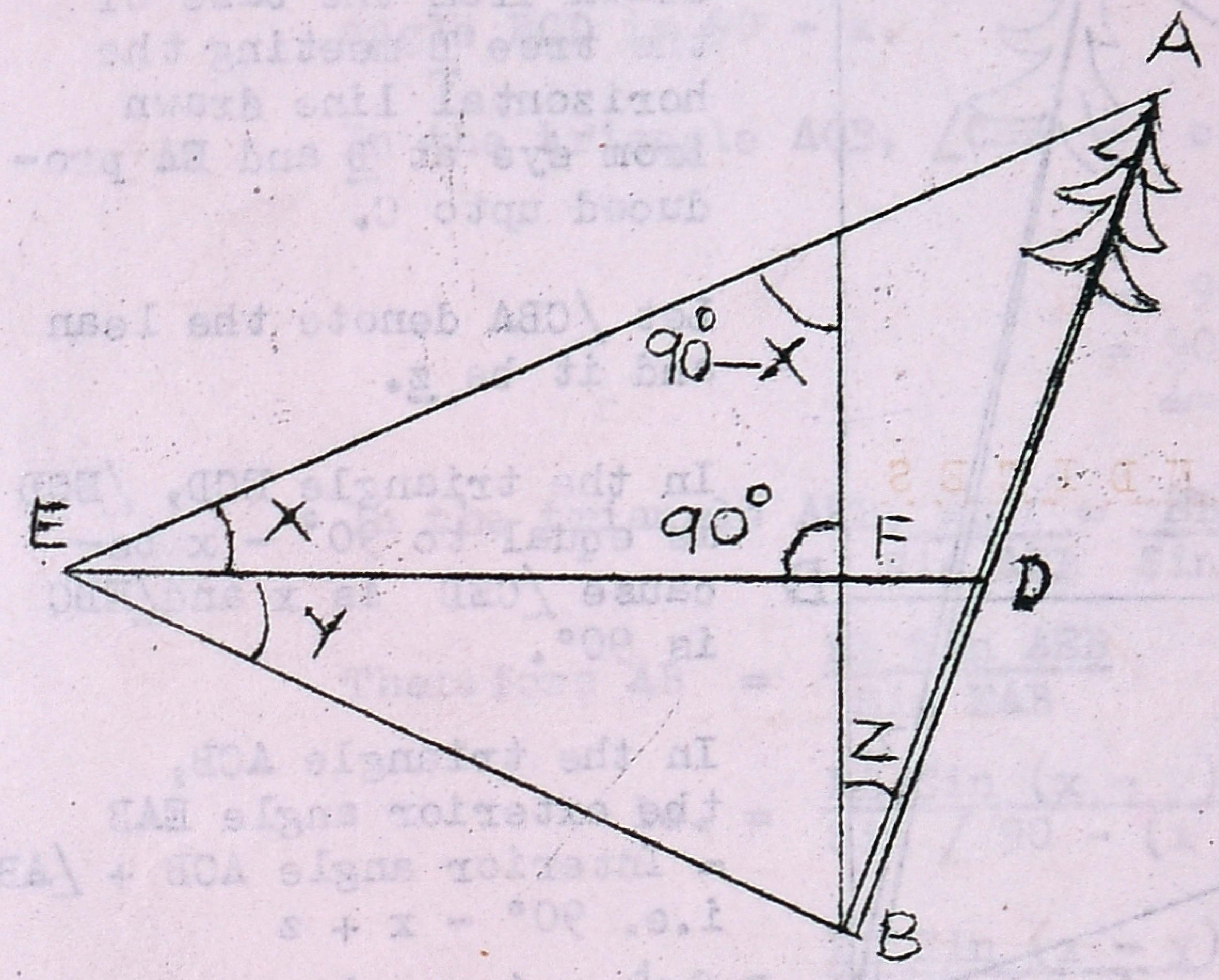
APPENDICES

APPENDIX 1

MEASUREMENT OF HEIGHTS OF LEANING TREES

Case 1: When the observer's eye level is between the base and top of tree.

a) Lean is away from the observer:



Let AB be the tree, E be the observer's eye and ED the horizontal line drawn from E cutting the tree at D. Let x and y be the angle of elevation (to the top of the tree) and depression (to the base of the tree) from E. Let BC be the vertical line drawn from the base of the tree B meeting AE the line of sight to the top of the tree at C and meeting the horizontal line CD and F. ∠CBA represents the angle of lean of the tree and let it be z.

In the Triangle ACB, the exterior angle ECB = Interior angle CAB +∠CBA.

Therefore∠CAB = ∠ECB - ∠CBA ..(i)

In the triangle ECF, ∠CEF is x°, ∠EFC is 90° and ∠ECF or ∠ECB is therefore 90 - x°. .... (ii)

Therefore equation (i) will be (90 - x) - z i.e. 90 - (x + z).

In triangle AEB,

$$\frac{AB}{\text{Sin } AEB} = \frac{EB}{\text{Sin } EAB}$$

$$\text{Hence } AB = \frac{EB \text{ Sin } AEB}{\text{Sin } EAB}$$

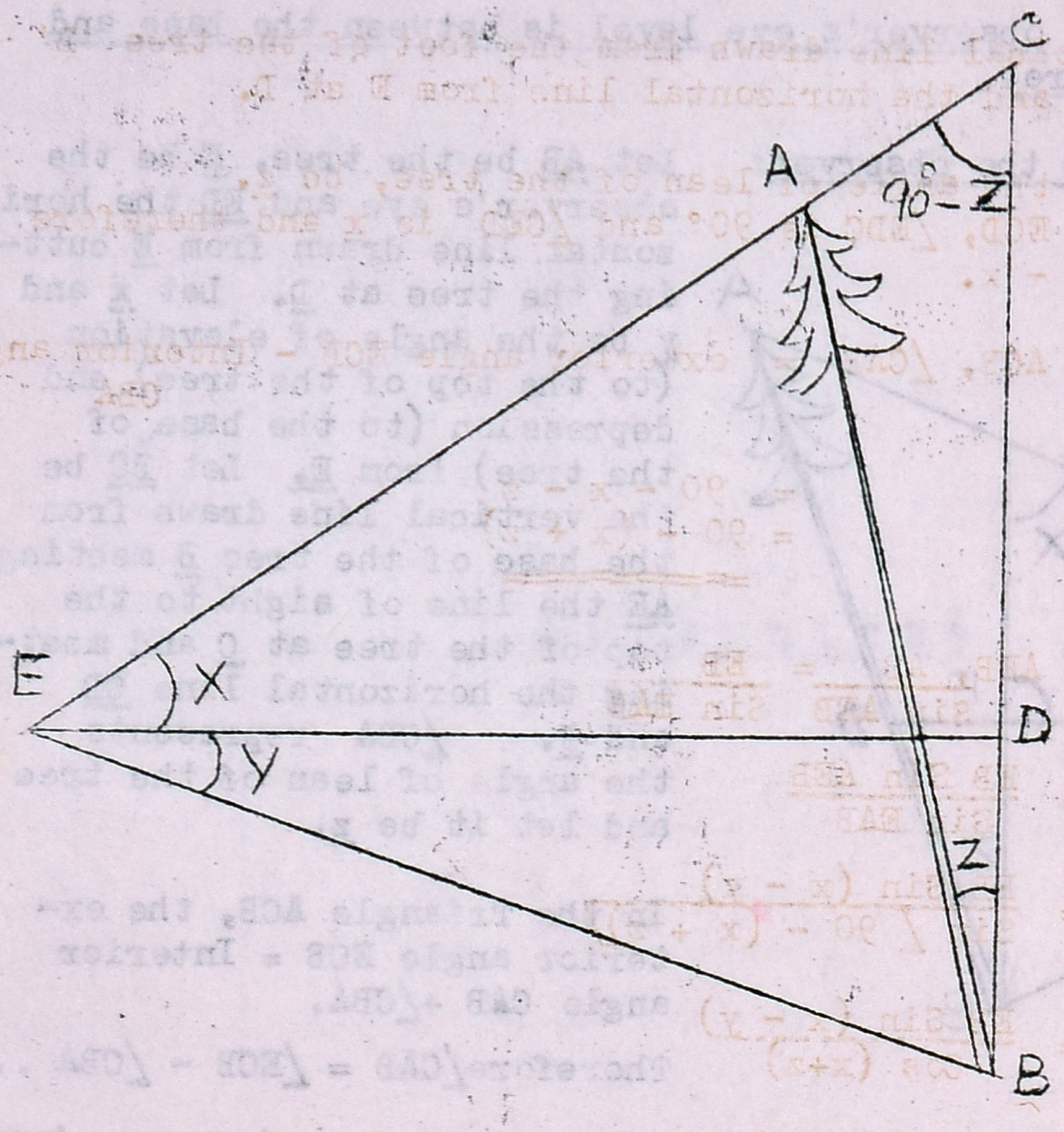
$$= \frac{EB \text{ Sin } (x + y)}{\text{Sin } (90 - (x+z)}$$

Since ∠CAB = ∠EAB

Further sin (90 - a) = Cos a is the rule.

$$\text{Hence } AB = \frac{EB \text{ Sin } (x + y)}{\text{Cos}(x + z)}$$

b) Same case - But Tree is leaning towards the observer.



Let AB be the tree leaning towards the observer. Let E be the observer. Let x and y be the angle of elevation and depression to the top and base of the tree respectively. Let BC be a vertical line drawn from the base of the tree B meeting the horizontal line drawn from eye at D and EA produced upto C.

Let $\angle CBA$ denote the lean and it be z.

In the triangle ECD, $\angle ECD$ is equal to $90° - x$ because $\angle CED$ is x and $\angle EDC$ is 90°.

In the triangle ACB, the exterior angle EAB = Interior angle ACB + $\angle ABC$ i.e. $90° - x + z$

$= 90 - (x - z)$

Now in the triangle AEB, $\dfrac{AB}{\text{Sin } AEB} = \dfrac{EB}{\text{Sin } EAB}$

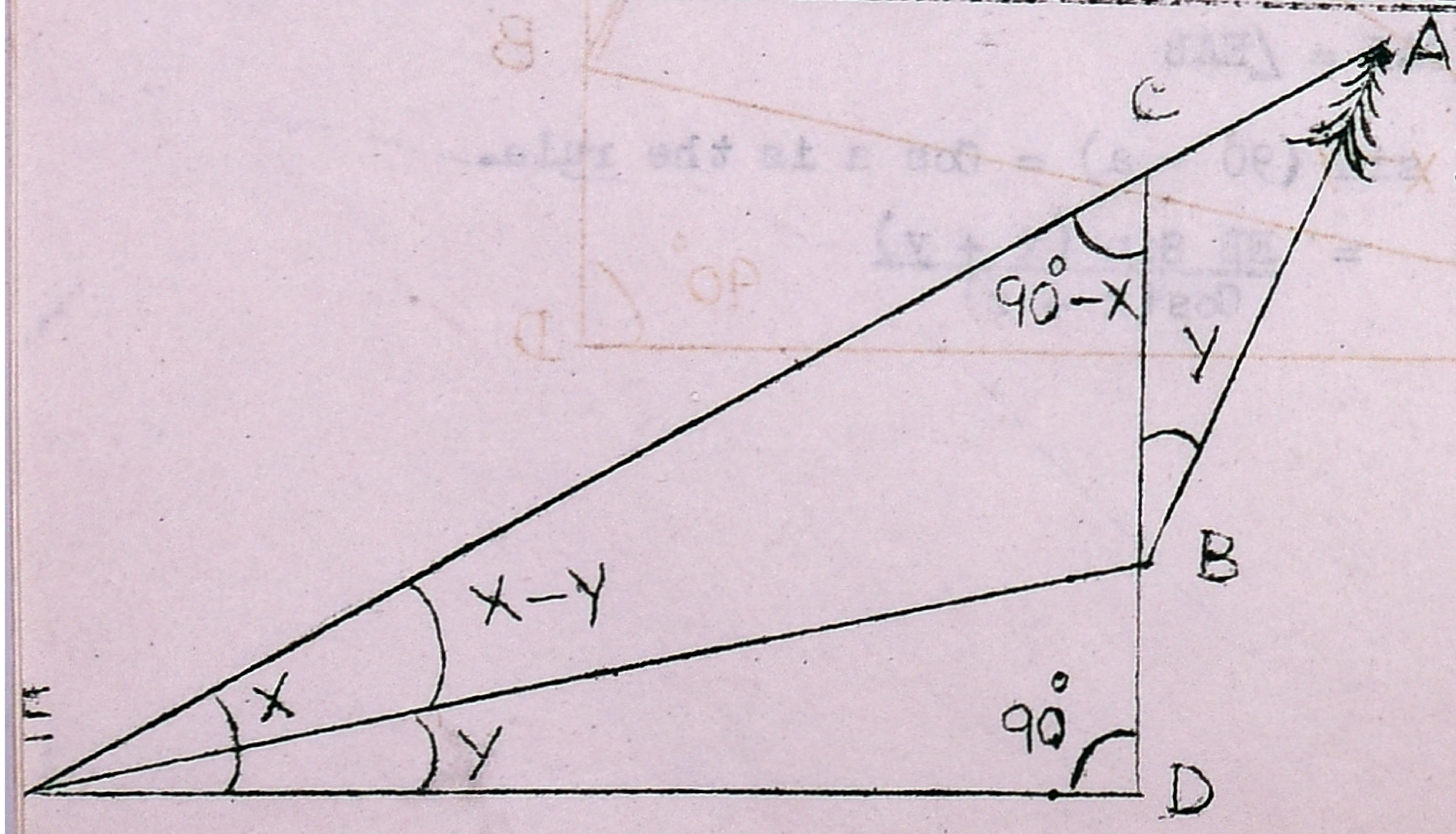
Therefore $AB = \dfrac{EB \text{ Sin } AEB}{\text{Sin } EAB}$

$= \dfrac{EB \text{ Sin } (x + y)}{\text{Sin } [90 - (x - z)]}$

i.e. $\dfrac{EB \text{ Sin } (x + y)}{\text{Cos } (x - z)}$

Case 2: The tree is above the observer's eye level.

(a) Lean is away from the observer.



Let AB be the tree leaning away from the observer.
Let $\underline{x}$ and $\underline{y}$ be the angle of the top and base of the tree from E.

Let BC be a vertical line drawn from the foot of the tree 'B' meeting EA at C and the horizontal line from E at D.

Let $\angle$CBA denote the angle of lean of the tree, be $\underline{z}$.
In the triangle ECD, $\angle$EDC is 90° and $\angle$CED is $\underline{x}$ and therefore angle ECD is 90 - x.

In the triangle ACB, $\angle$CAB = exterior angle ECB - Interior angle CBA

$$= 90 - x - z$$
$$= 90 - (x + z)$$

In the triangle AEB, $\frac{AB}{\text{Sin AEB}} = \frac{EB}{\text{Sin EAB}}$

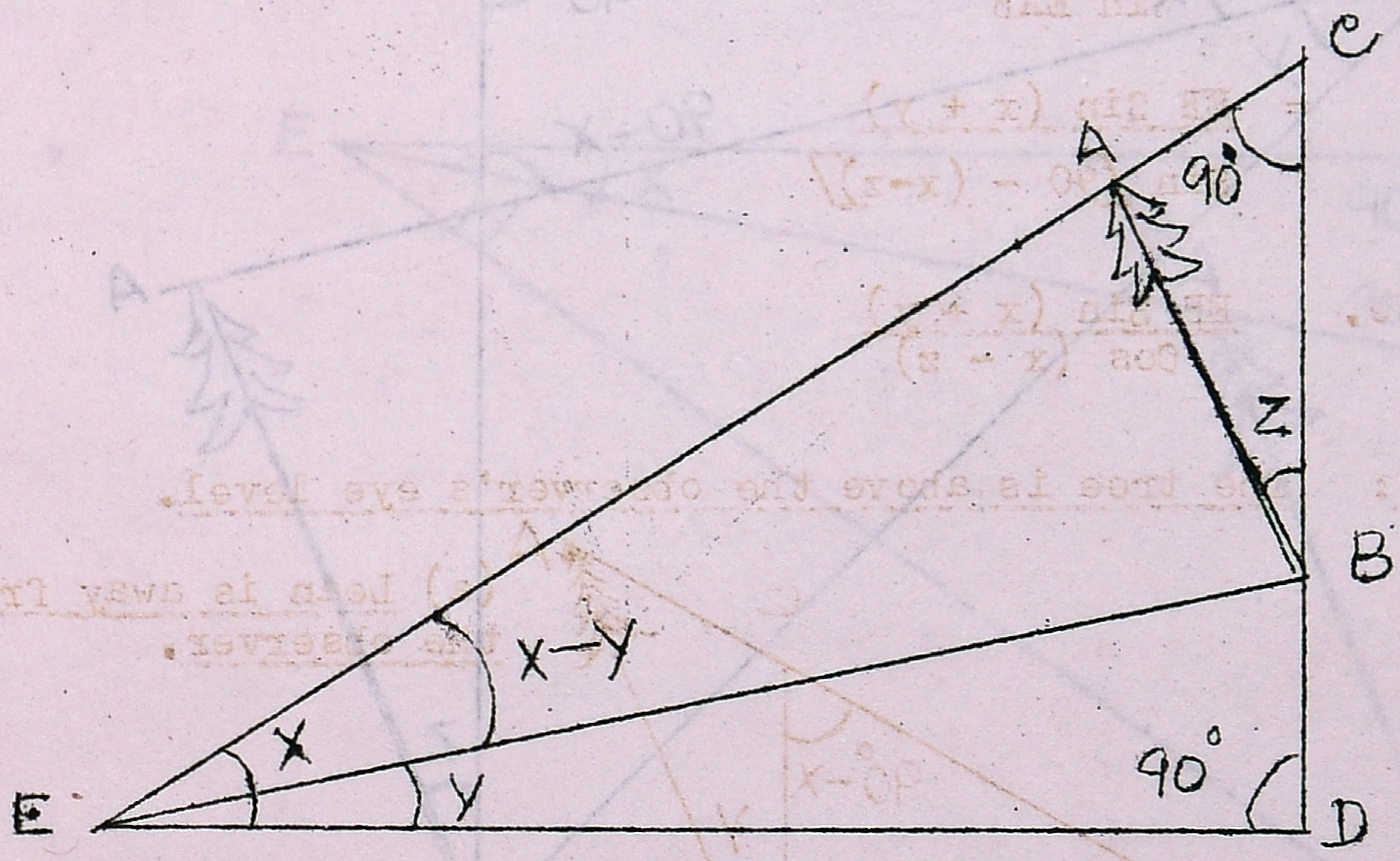
Therefore AB $= \frac{\text{EB Sin AEB}}{\text{Sin EAB}}$

ie. $= \frac{\text{EB Sin }(x - y)}{\text{Sin } \angle 90 - (x + z)\rceil}$

i.e.$= \frac{\text{EB Sin }(x - y)}{\text{Cos }(x+z)}$

Since $\angle$ EAB = $\angle$CAB.

b) <u>Tree is above observer's eye level but the leaning of tree is towards the observer.</u>



Let AB be the tree leaning towards the observer.
Let x and y be the angles to the top and base of the tree from E.
Let BC be a vertical line drawn from the foot of the tree B meeting EA produced at C and the horizontal line from observer's eye at D.

Let $\angle CBA$ be the lean of tree and be z.

In the triangle ECD, $\angle ECD = 90 - x$, since $\angle DEC$ is x and $\angle EDC$ is 90°.

In the triangle ACB, exterior $\angle EAB$ = Interior $\angle ACB + \angle ABC$

$$= 90° - x + z$$

$$= 90 - (x - z)$$

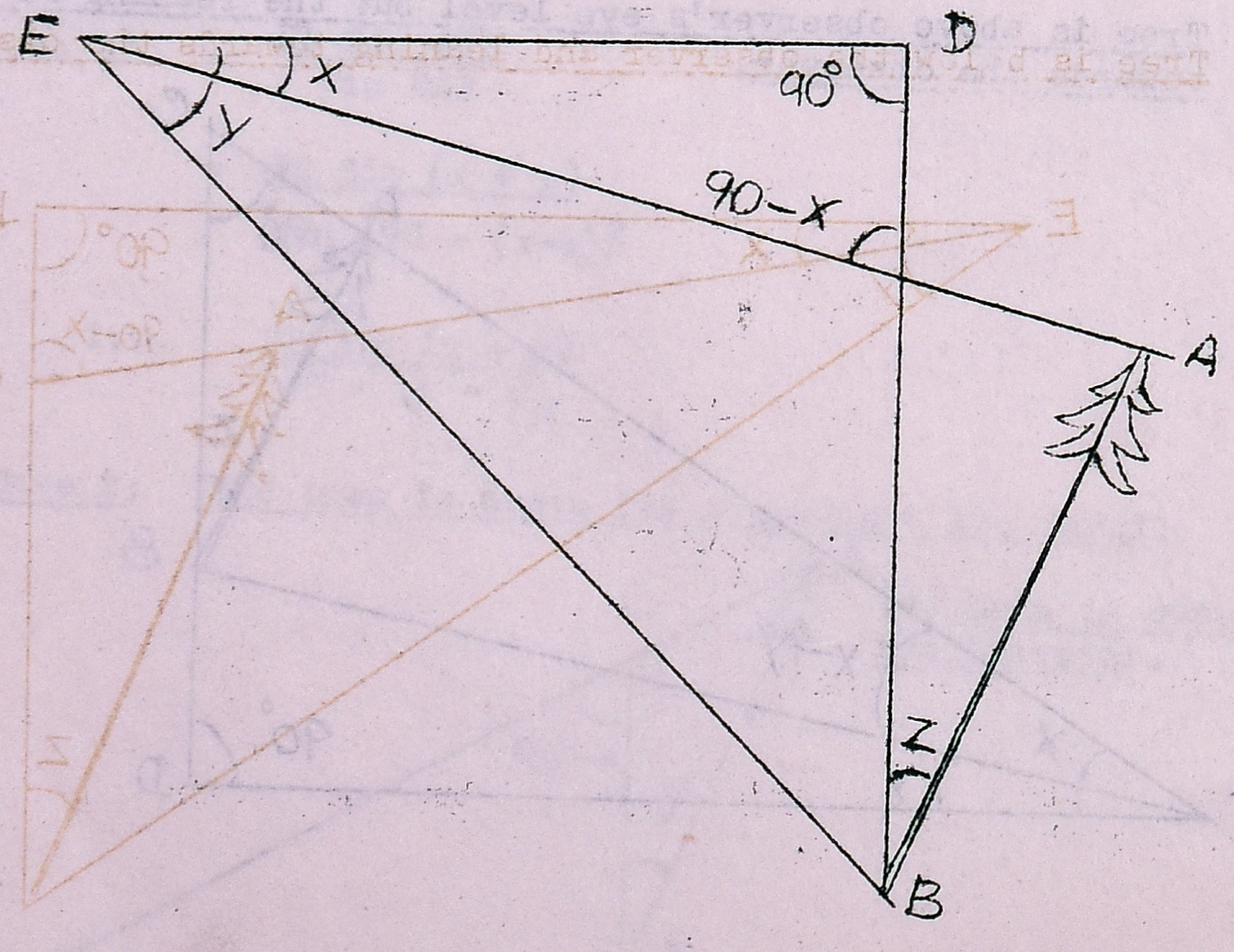
In the triangle ACB, $\frac{AB}{\text{Sin } AEB} = \frac{EB}{\text{Sin } EAB}$

Therefore $AB = \frac{EB \sin AEB}{\text{Sin } EAB}$

$$= \frac{EB \text{ Sin } (x - y)}{\text{Sin } [90-(x-z)]}$$

$$= \frac{EB \text{ Sin } (x - y)}{\text{Cos } (x - z)}$$

Case 3: The tree is below the observer and the lean is away from the observer.



Let AB be the tree leaning away from the observer.
Let x and y be the angles to the top and bottom of the tree from E.
Let BC be a vertical line drawn from the foot of the tree B meeting AE at C and the horizontal line drawn from observer's eye at D.
Let $\angle CBA$ be the angle of lean of tree and be z.

In the triangle ECD, $\angle ECD$ is $90° - x = \angle ACB$ since they are opposite angles.

In the triangle ACB, $\angle CAB = 180° - (\angle ACB + \angle ABC)$

$$\text{i.e. } 180 - (90 - x + z)$$

$$= 90 + (x - z) \qquad \text{Sin } (90 + a) = \text{Cos } a \text{ is the Rule}$$

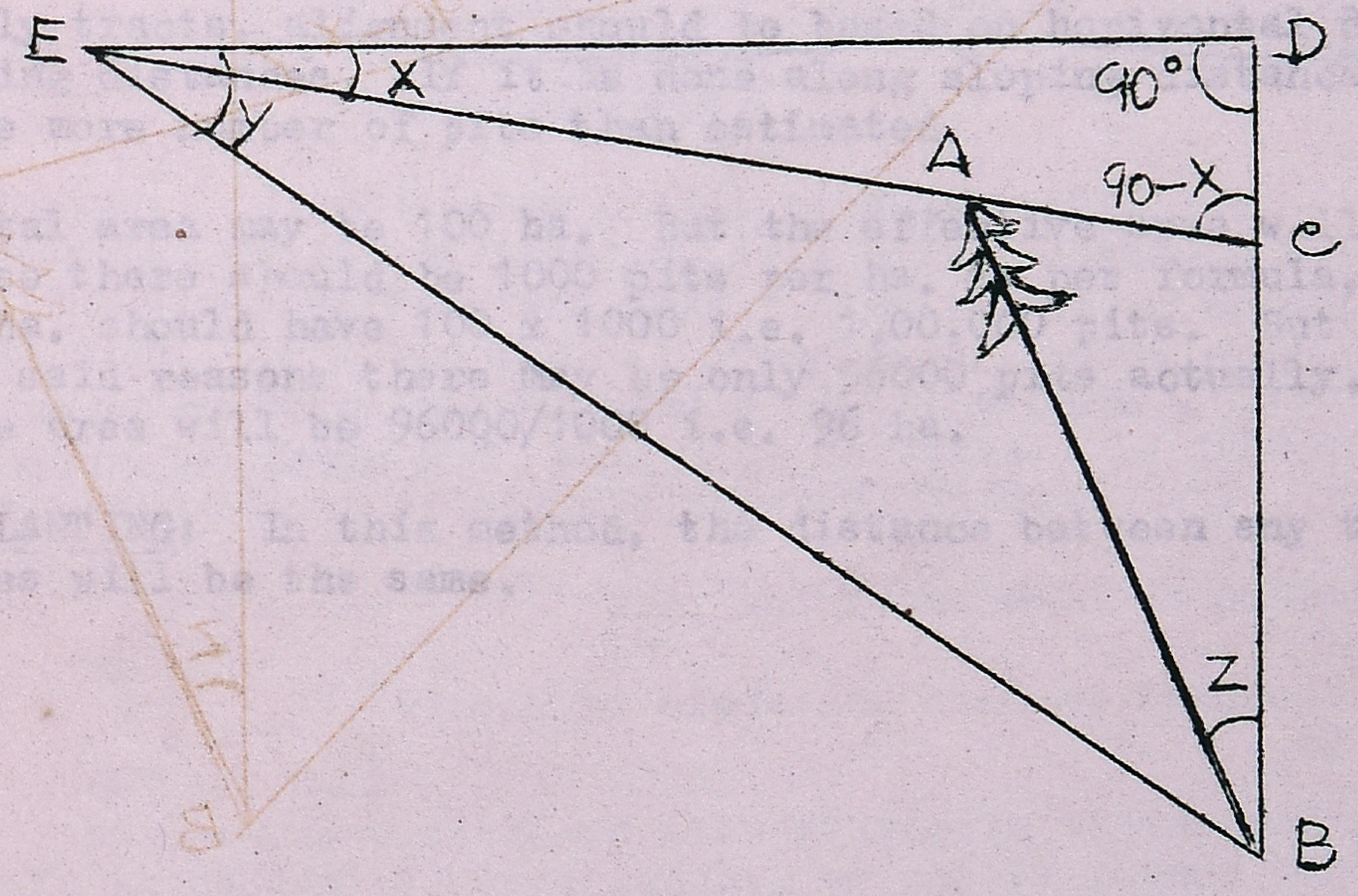
Now in the triangle AEB, $\frac{AB}{\text{Sin } AEB} = \frac{EB}{\text{Sin } EAB}$

$$\text{Hence } AB = \frac{EB \text{ Sin } AEB}{\text{Sin } EAB}$$

$$= \frac{EB \text{ Sin } (y - x)}{\text{Sin } \angle 90° + (x - z)}$$

$$= \frac{EB \text{ Sin } (y - x)}{\text{Cos } (x - z)}$$

b) <u>Tree is below the observer and leaning towards the observer.</u>



Let AB be the tree leaning towards the observer.
Let x and y be the angle to the top and base of tree from E.
Let BD be vertical line drawn from the foot of tree B, meeting EA produced at C and the horizontal line drawn from eye at D.

Let $\angle ABC$ be lean of tree i.e. z.
In the triangle ECD, exterior angle ECB = Interior angle CED + $\angle$EDC

i.e. $x + 90°$
i.e. $90 + x$.

In the triangle ACB, exterior angle EAB = Interior angle ACB + $\angle$ABC

$$= 90 + x + z$$

$$= 90 + (x + z)$$

Now in the triangle AEB, $\dfrac{AB}{\text{Sin } AEB} = \dfrac{EB}{\text{Sin } EAB}$

Hence $AB = \dfrac{EB \text{ Sin } AEB}{\text{Sin } EAB}$

$$= \frac{EB \sin (y - x)}{\text{Sin } \angle 90 + (x+x)/}$$

Sin (90 + a) = Cos a is the Rule.

$$= \frac{EB \text{ Sin } (y - x)}{\text{Cos } (x + z)}$$

APPENDIX 2

ESPACEMENTS AND NUMBER OF PLANTS

1. INTRODUCTION: Forest Department is engaged in raising of several plantations under several schemes to supply the increasing needs of the forest produce. Hence it is quite essential that a Ranger should know to prepare the estimates for raising of such plantations for raising the nursery, digging pits, planting, weeding, application of fertilizers, etc. Unless and until he knows the number of plants per hectare, he will not be able to proceed further.

2. Methods of spacing: Generally the following methods of spacings are adopted in raising the plantations.

i) Line or rectangular planting.
ii) Square planting.
iii) Quincunx planting
iv) Triangular planting.

3. The following formula can be used for finding out the number of plants per hectare. But there will be difference between the number of pits calculated as per formula and the actual number of pits due to the following reasons.

i) We presume that the planting area will be rectangular. But the area will be with all sorts of irregular shape.

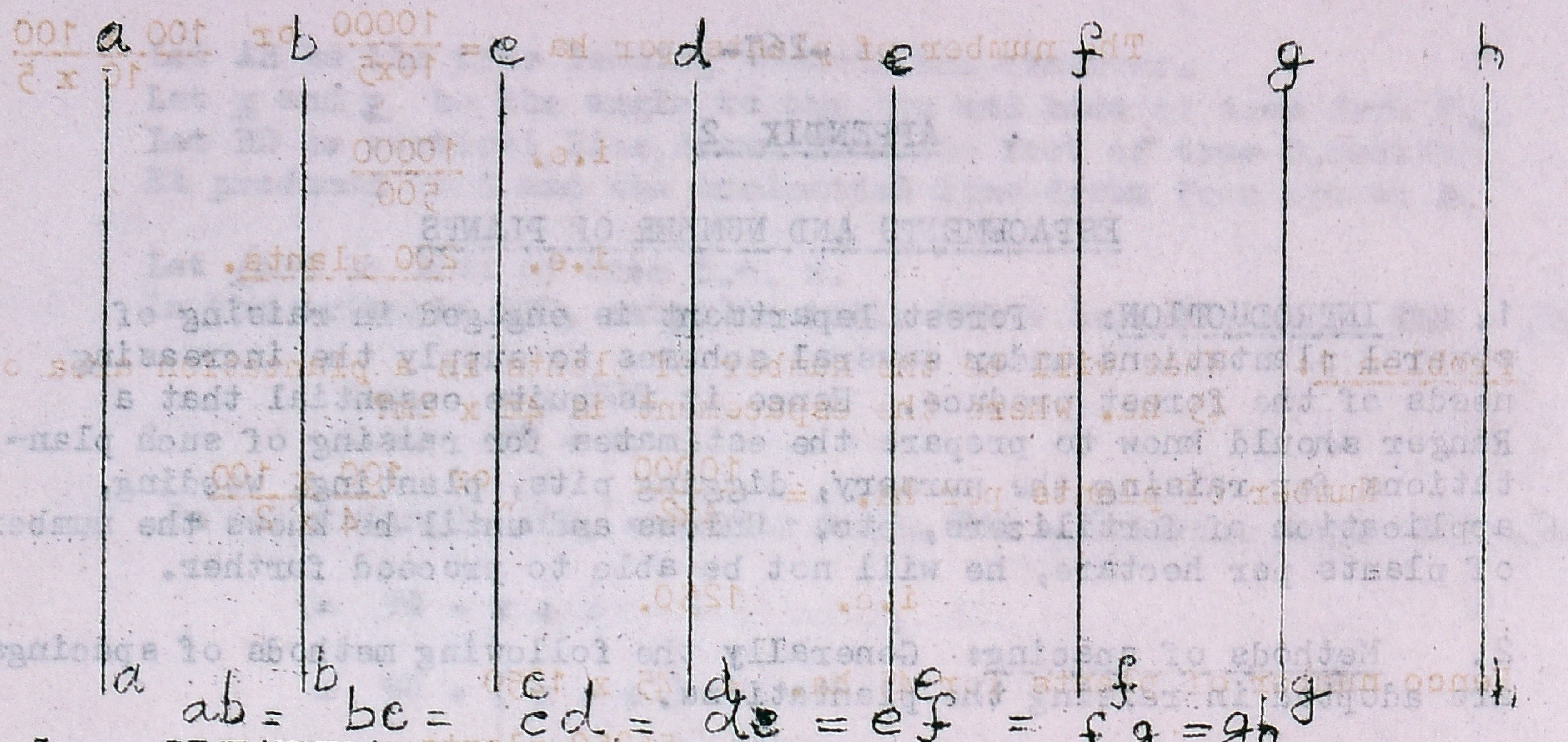
ii) There may be several small patches which may be stony, gravelly, swampy, saline, etc. where planting will not be done. There may be a small river running through the plot which will not be planted.

iii) While doing alignment, there may be difference due to wrong measurements, stretching of ropes, etc.

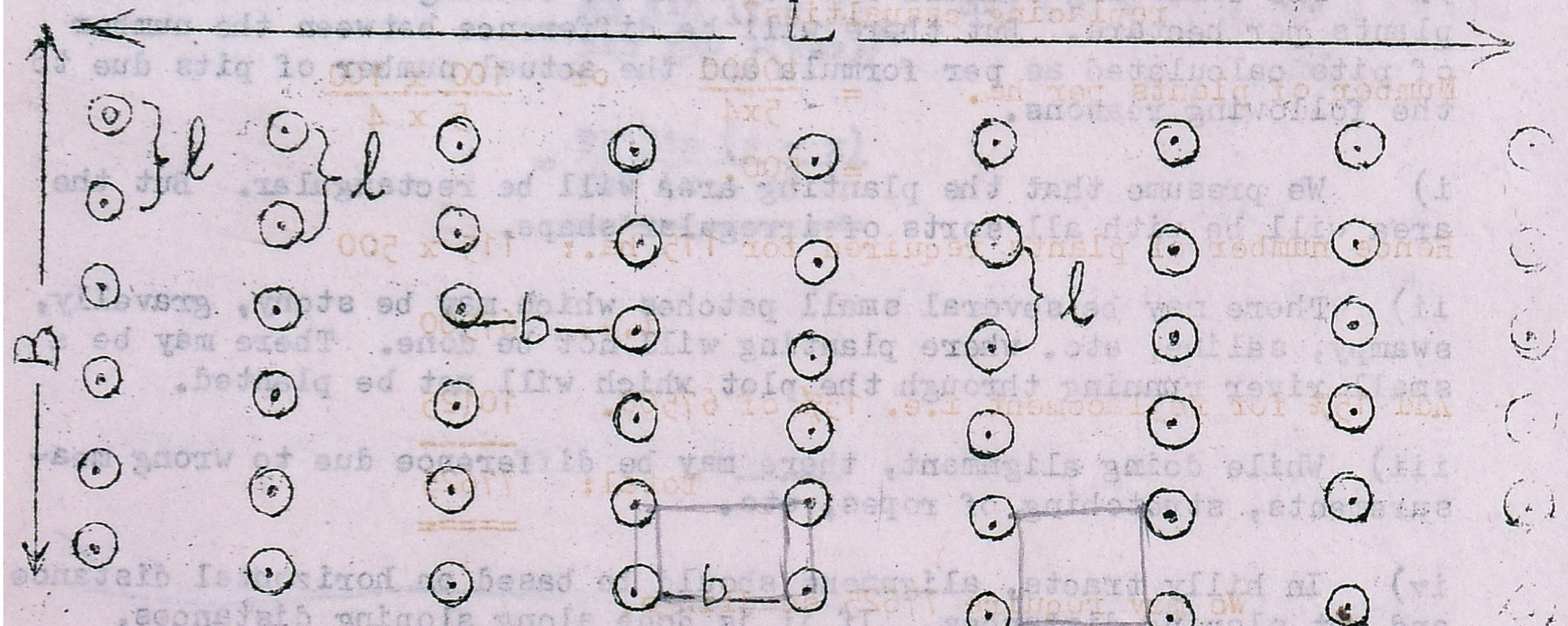
iv) In hilly tracts, alignment should be based on horizontal distance and not sloping distances. If it is done along sloping distances, there will be more number of pits than estimated.

The total area may be 100 ha. But the effective area will be less. Suppose there should be 1000 pits per ha. as per formula, an area of 100 ha. should have 100 x 1000 i.e. 1,00,000 pits. But due to the above said reasons there may be only 96000 pits actually. Then the effective area will be 96000/1000 i.e. 96 ha.

4. LINE PLANTING: In this method, the distance between any two adjacent lines will be the same.



5. RECTANGULAR PLANTING: In this method the distance between any two adjacent lines will be the same. Similarly the distance between any two plants in the planting line will also be the same. This will result in the formation of a rectangle with 4 adjacent plants as shown in the sketch.



-- Lines ⊙ Plants L = Length of plantation in metres
B = Breadth of plantation in metres b = distance between lines in metres l = Distance between the plants in the lines in metres.

In this case the area of the plot = L x B

Area occupied by each rectangle of plants will be } l x b

Hence the number of plants will be LB/lb.
From the above, it can be deduced that the number of plants per ha. will be $\frac{\text{Area in sq. metres}}{\text{Area occupied by plants for each rectangle}}$

i.e. $\frac{10000 \text{ sq. metres}}{l \times b}$ or $\frac{100M \times 100\ M}{L \times B}$

Example: Let the espacement be 10m x 5m.

The number of plants per ha $= \frac{10000}{10x5}$ or $\frac{100 \times 100}{10 \times 5}$

i.e. $\frac{10000}{500}$

i.e. 200 plants.

Problem 1: What will be the number of plants in a plantation area of 45 ha. where the espacement is 4m x 2m?

Number of plants per ha. $= \frac{10000}{4x2}$ or $\frac{100 \times 100}{4 \times 2}$

i.e. 1250.

Hence number of plants for 45 ha. = 45 x 1250

= 56250 plants.

Problem 2: What will be number of nursery seedlings for raising plantation over an area of 115 ha. which is to be planted at an espacement of 5m x 4m - with 15% of provision for replacing casualties?

Number of plants per ha. $= \frac{10000}{5x4}$ or $\frac{100 \times 100}{5 \times 4}$

= 500.

Hence number of plants required for 115 ha.: 115 x 500

i.e. 67500

Add 15% for replacement i.e. 15% of 67500. 10125

Total: 77625

We may require 77625 seedlings.

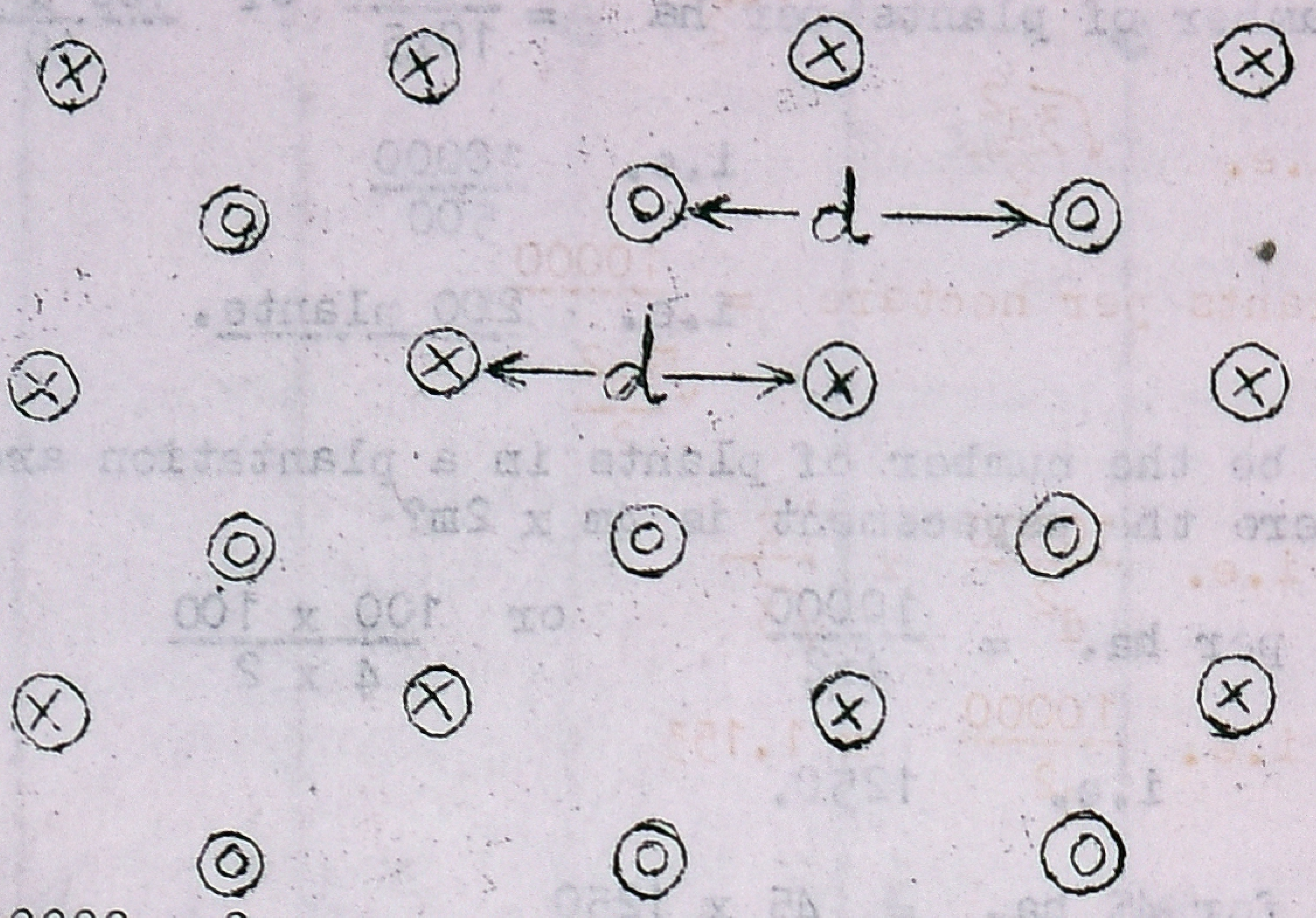
6. Square planting: In this case l will be equal to b, i.e. the distance between the adjacent lines as well as the distance between the plants in the lines will be the same. Planting at an espacement of 2m x 2m, 4m x 4m, 10m x 10m are all examples of square planting. The formula for calculating the number of pits per hectare will be the same i.e. $\frac{\text{Area in sq. metres}}{\text{Area of square}}$ or 10000/espacement.

Example: If espacement is 5m x 5m the number of plants per ha. will be

$= \frac{10000}{5x5}$

i.e. 400 plants.

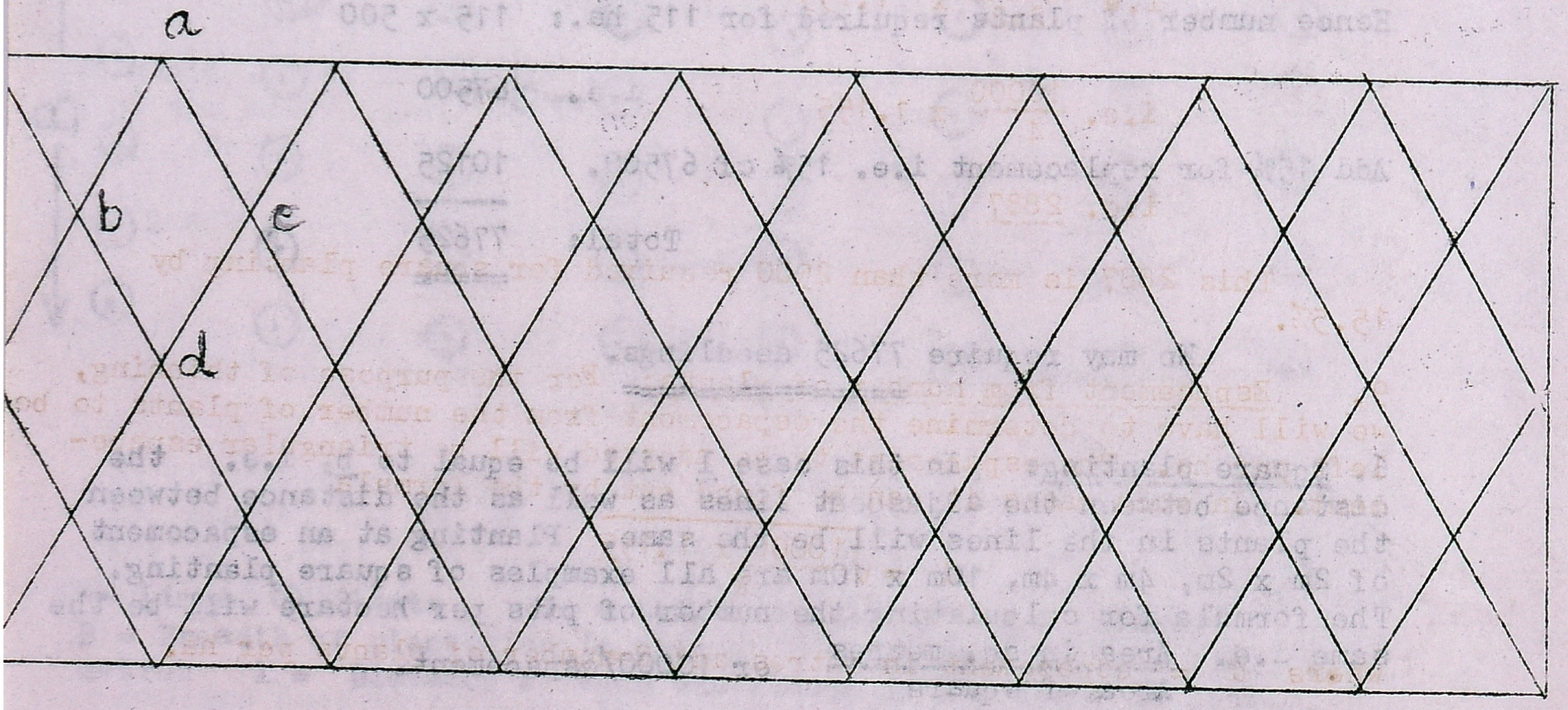
7. QUINCUNX PLANTING: This consists of square planting with an additional plant planted at the centre of each square which will have the effect of doubling the number of rows, each row containing the same number of plants. Quincunx means five. Hence the number of plants in quincunx planting will be double the number of plants under square planting with the same espacement. Hence the number of plants per ha. under quincunx planting will be equal to



$\frac{10000 \times 2}{d^2}$ where d represents the side of the square in metres.

Example: If quincunx planting is done at 2m x 2m the number of plants per ha. will be $\frac{10000 \times 2}{2 \times 2}$ i.e. 5000 plants.

8. TRIANGULAR PLANTING: In this type of planting, the positions of 3 adjacent plants will occupy the corners of an equilateral triangle. If the distance between the plants are d metre, the area occupied by 4 adjacent plants will be $\sqrt{3}d^2/4$ as follows.



Triangular planting

In the above figure abcd is parallelogram abcd = Twice the triangle abc.

Area of $\triangle$ abc $= 1/2\ d \times \frac{\sqrt{3}}{2} d$

Hence area of abcd $= 1/2 \times d \times \frac{\sqrt{3}d}{2} \times 2$

i.e. $\frac{\sqrt{3}d^2}{2}$

Hence number of plants per hectare $= \frac{10000}{\frac{\sqrt{3}d^2}{2}}$

i.e. $\frac{10000}{d^2} \times \frac{2}{\sqrt{3}}$

i.e. $\frac{10000}{d^2} \times 1.155$

This means there will be 1155 plants under Triangular planting instead of 1000 plants under square planting. Hence there will be an addition of 155 plants for 1000 plants. Hence there will be 15.5% of additional plants under Triangular planting than under square planting.

<u>Example</u>: The number of plants required for planting up an area with triangular espacement of 2 metres will be

$\frac{10000}{2x2} \times \frac{2}{\sqrt{3}}$

i.e $\frac{10000}{2x2} \times 1.155$

i.e. $\frac{10000}{4} \times 1.155$

i.e. <u>2887</u>

This 2887 is more than 2500 required for square planting by 15.5%.

9. <u>Espacement from number of plants</u>: For the purpose of thinning, we will have to determine the espacement from the number of plants to be left per ha. The espacement to be adopted will be triangular espacement. In such cases it can be found out by the formula

$$d = \sqrt{\frac{10000 \times 1.155}{N}}$$

where d = espacement in metres and N=number of plants per ha.

<u>Example</u>: The number of plants that are to be left per ha. with triangular espacement is 220 as per yield tables. What will be espacement you will adopt for thinning?

$$d = \sqrt{\frac{10000 \times 1.155}{220}}$$

i.e. $\sqrt{\frac{11550}{220}}$

i.e. $\frac{107.47}{14.83}$

$= \underline{7.25\ m.}$

Problems:

1. What will be the total cost of earthwork if a plantation is raised with 60cm cube pits with the following espacements over an area of 100 ha?

a) Rectangular planting 4 x 2.5m. = 25 ha.
b) Square planting 4m x 4m = 25 ha.
c) Quincunx planting 5m = 25 ha.
d) Triangular planting 6m = 25 ha.
e) Rate of earthwork = Rs.12.00/m^3.

a) Rectangular planting:

Number of pits in 25ha at 4 x 2.5 m. $\frac{10000}{4 \times 2.5} \times 25$

= 25000 pits.

The quantity of earthwork per pit = 0.6 x 0.6 x 0.6

i.e. 0.216m^3

Rate is 12.00 per m^3.
Hence rate per pit is 12 x 0.216 = 2.592.
Cost of earth work for 25000 pits will be 25x2.592 = Rs.64800.00

b) Square planting: 4m x 4m

Number of pits per 25 ha. = $\frac{10000}{4 \times 4} \times 25$

= 15625 pits.

Cost for 15625 pits at 2.592 per pit = 15625 x 2.592
= Rs.40,500.00

c) Quincunx planting of 5m.

Total number of pits in 25 ha. = $\frac{10000}{5 \times 5} \times 2 \times 25$

= 20000 pits.

Cost of earthwork for 20000 pits at 2.592 / pit. 20000 x 2.592

i.e. Rs.51840.00

d) Triangular planting 6m.

Total number of pits in 25 ha. = $\frac{10000}{6 \times 6} \times 1.155 \times 25$

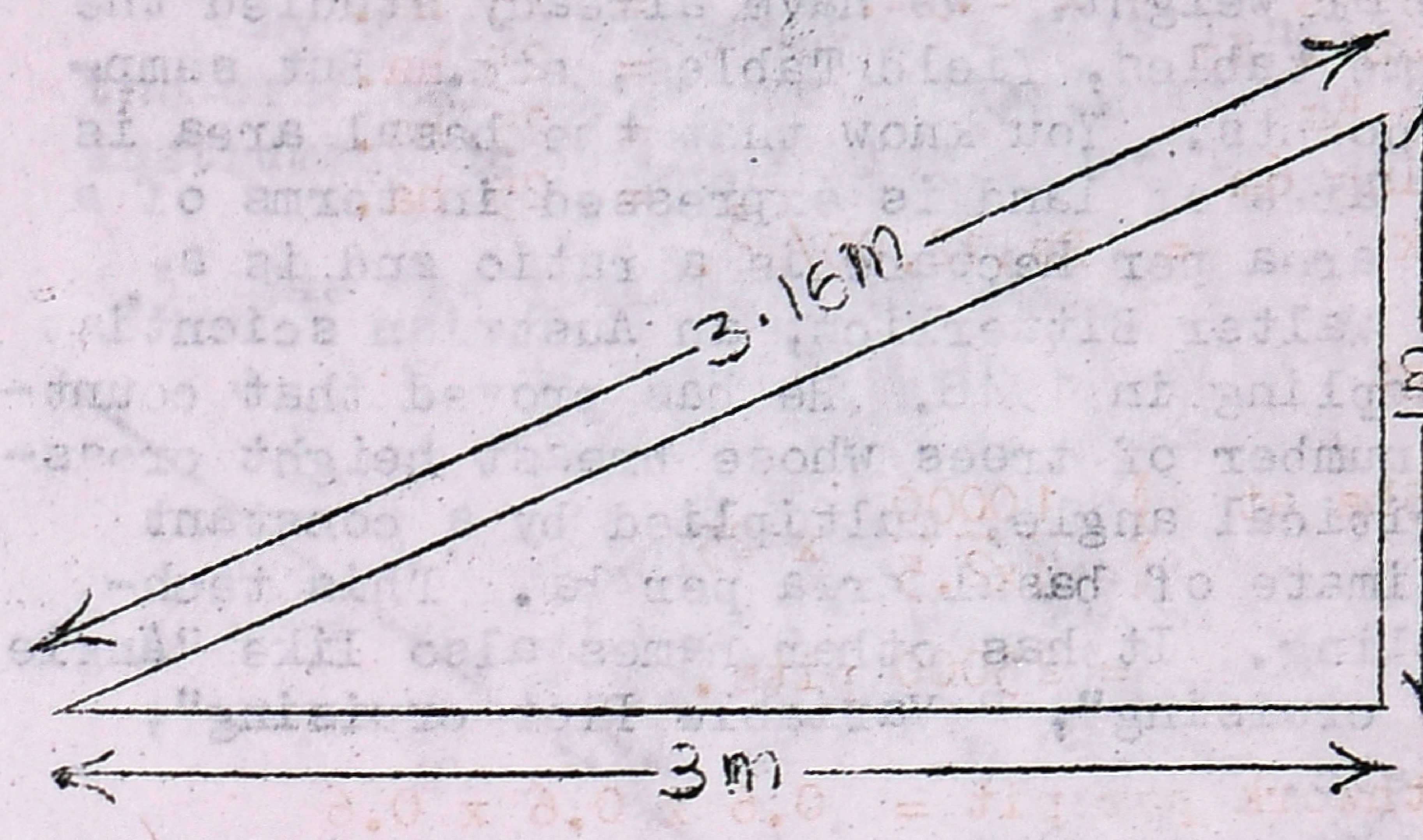
i.e. 8020 pits.

Cost of earthwork for 8020 pits at 2.592/pit. 8020 x 2.592

= 20787.84

Total cost will be Rs.64800 + 40500 + 51840 + 20787.84 = Rs.177927.84

2. In a hilly country, having a slope of 1 in 3, a plantation was raised over an area of 75 ha. at an espacement of 3m x 3m. But alignment was done by measuring along the slope. How many plants would have been planted as extra?



See the figure showing 1 in 3 slope. If the horizontal distance is 3m, the sloping distance will be

$$\sqrt{3^2 + 1^2}$$

i.e. $\sqrt{10}$

i.e. 3.16 m.

Instead of planting one plant at every 3.16m, it has been planted at 3m.

If spacing is 3.16 x 3.16 the number of pits in 75 ha

$$= \frac{10000}{3.16 \times 3.16} \times 75$$

i.e. 75108 pits.

If spacing is 3m x 3m, the number of pits in 75 ha.

$$= \frac{10000}{3 \times 3} \times 75$$

i.e. 83333 pits.

Hence extra pits are 83333 - 75108

i.e. 8225 pits.

3. If the number of plants to be left after doing thinning in a teak plantation is 500 per ha. what is the triangular espacement to be adopted to do thinning?

$$d = \sqrt{\frac{10000 \times 1.155}{500}}$$

i.e. $\sqrt{11550/500}$

i.e. 4.8 m.

APPENDIX 3

PRINCIPLE AND PRACTICE OF POINT SAMPLING BY WEDGE PRISM

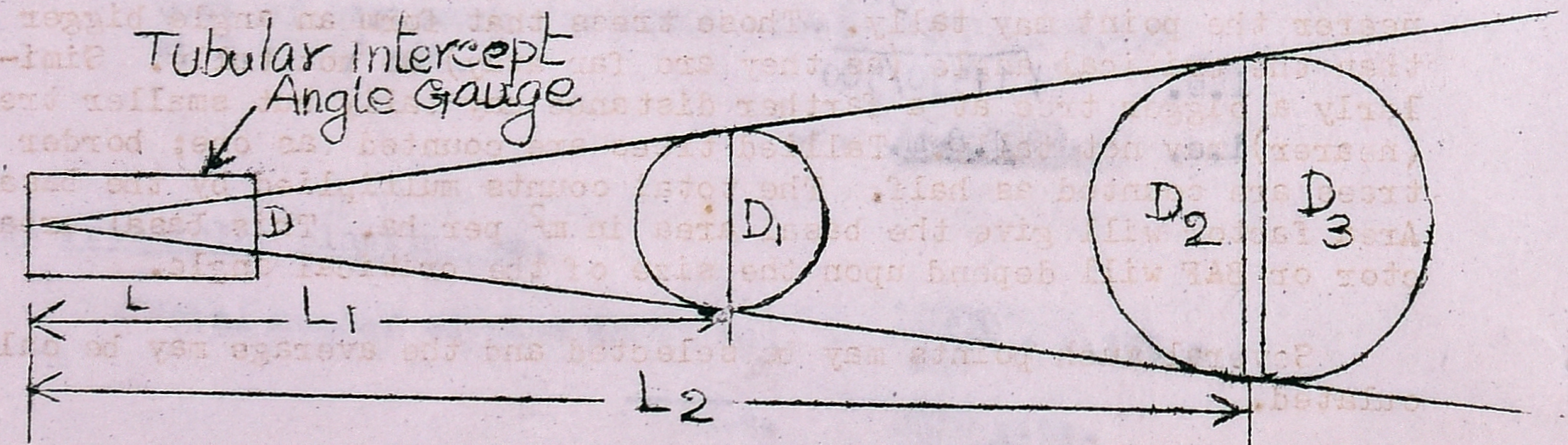
1. Introduction: The object of mensuration is only to estimate the yield in terms of volume or weight. We have already studied the method of sample plots, volume tables, Yield Tables, etc. But sampling units may also be just points. You know that the basal area is expressed in terms of m^2 and area of land is expressed in terms of a ha. or $10000m^2$. Hence basal area per hectare is a ratio and is a dimension-less measure. Mr. Walter Bitterlich, an Austrian scientist found the theory of point sampling in 1948. He has proved that counting from a random point the number of trees whose breast height cross-section exceeds a certain critical angle, multiplied by a constant factor gives an unbiased estimate of basal area per ha. This technique is known as Point Sampling. It has other names also like "Angle count cruising". "Pointless cruising", " Variable Plot cruising", "Poly-areal plot sampling", etc.

2. Kinds of Point Sampling: Point Sampling may be horizontal or vertical depending upon whether diameter or height is to be estimated. Only horizontal sampling has been widely used in all the places.

3. Advantages: No laying of sample plot is required. No felling of trees - No measurement of diameter or girth is involved. We can get the total basal area per unit area in a single operation. This simplicity may fecilitate us in taking larger sample points to cover the variation in growth which will add precision of estimate. Being simple and precise it has become very popular.

4.1 Concept of Horizontal Sampling: Select one point. The trees around this point are viewed through any angle-gauge at breast height level. All the trees forming an angle bigger than the critical angle of the instrument are counted. Let us consider a Intercept angle gauge.

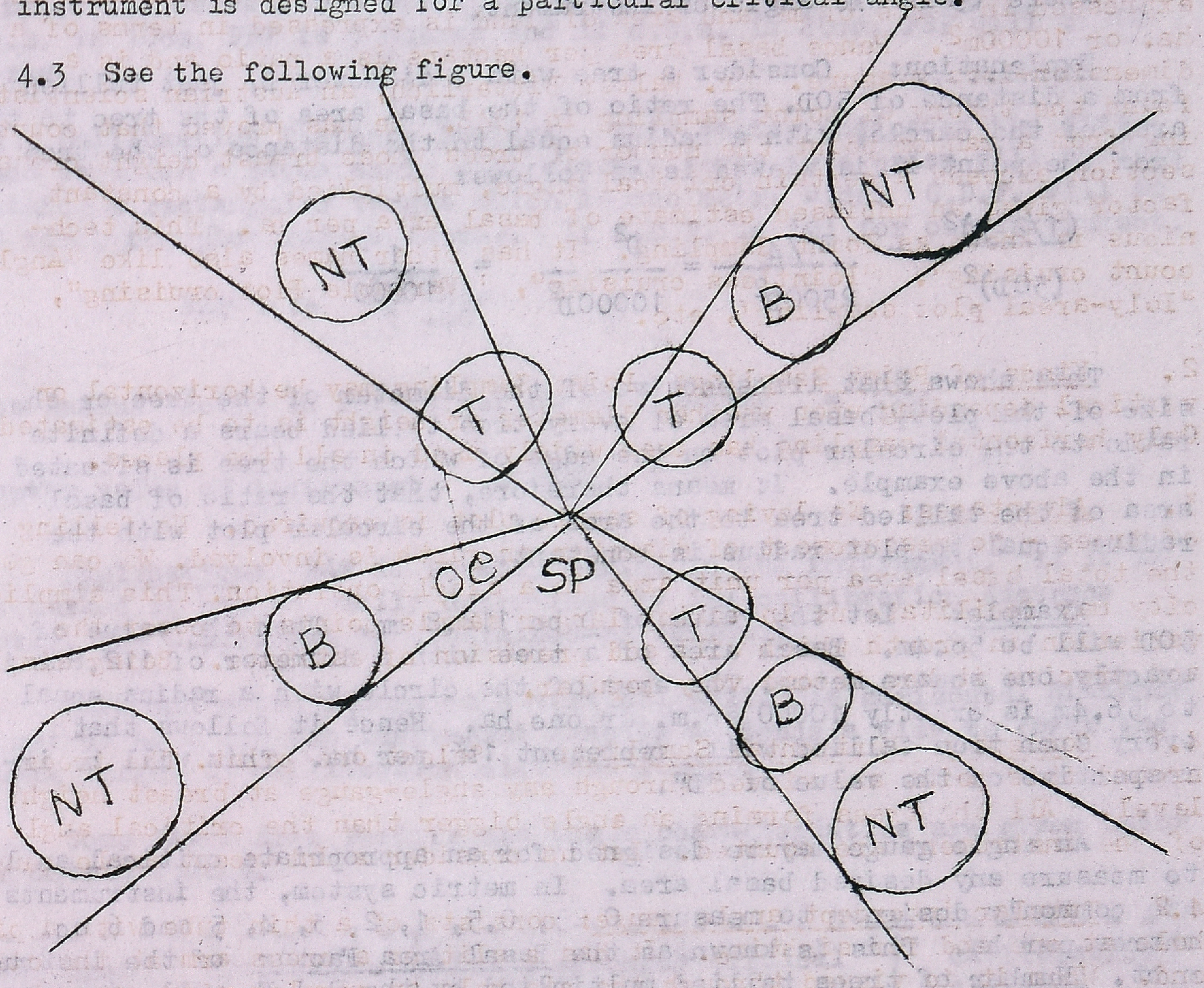
4.2 Tubular intercept angle gauge: consists of a thin tube with a pin hole at one end for sighting. It has a slit or a cross arm at the other end. When it is viewed through the pin hole an angular view, as subtended by the slit is seen, which widens with distance. This is known as the critical angle of the instrument. This is decided by the ratio of the slit length to the length of the instrument.



If this ratio is 1/100, the critical angle will be 34.38 minutes. If the ratio is 1/50, the critical angle is 68.76 minutes. The critical angle is measured in terms of Diopters. One diopter is approximately equal to 34.38 minutes and corresponds to a ratio of 1/100.

By proper variation of slit length and length of the instrument, the critical angle can be designed for any desired value. Hence each instrument is designed for a particular critical angle.

4.3 See the following figure.



S.P. is the sampling point. T are the trees that have been tallied. B are the border line trees. N.T. denotes the trees have not been tallied. The critical angle of the instrument is Θ. Though all the trees may have equal basal area, only some will tally. The trees nearer the point may tally. Those trees that form an angle bigger than the critical angle (as they are far away) do not tally. Similarly a bigger tree at a farther distance may tally but smaller trees (nearer) may not tally. Tallied trees are counted as one; border trees are counted as half. The total counts multiplied by the Basal Area factor will give the basal area in m^2 per ha. This basal area factor or BAF will depend upon the size of the critical angle.

Several such points may be selected and the average may be calculated.

5. Definition of certain terms:

5.1 Diopter: This is a measure of the value of an angle expressed as its Sine. One diopter is approximately equivalent to an angle of 0.57° or 34.36 minutes since sin 0.57° = 1/100 = 1 diopter.

5.2 Basal area factor (B.A.F): This is the multiplying factor associated with any instrument. If the instrument gives basal area in square metres per hectare, then

$$B.A.F. = 2500k^2$$

$$= 10000 \sin^2 \frac{\theta}{2} \text{ as } k = 2 \sin \frac{\theta}{2}$$

where θ is the angle of instrument.

Explanation: Consider a tree with a diameter D, just tallied from a distance of 50D. The ratio of the basal area of the tree to the area of the circle, with a radius equal to the distance of the tree from the point it is viewed is as follows:

$$\frac{(1/2\ D)^2}{(50D)^2} = \frac{D^2/4}{2500D^2} = \frac{D^2}{10000D^2} = \frac{1}{10000}$$

This shows that irrespective of the diameter of the tree or the size of the plot, basal area of every tree tallied bears a definite ratio to the circular plot on the edge of which the tree is situated in the above example. It means therefore, that the ratio of basal area of the tallied tree to the area of the circular plot with the radius equal to plot radius is constant.

Example: Let the value of D be 112.8 cm. Then the value of 50D will be 56.4m. Basal area of a tree with a diameter of 112.8cm is exactly one square metre. The area of the circle with a radius equal to 56.4m is exactly 10000 sq.m. or one ha. Hence it follows that every such tree tallied will represent $1m^2$ per ha. This will be irrespective of the value of "D".

An angle gauge may be designed for an appropriate critical angle to measure any desired basal area. In metric system, the instruments are commonly designed to measure 0.25, 0.5, 1, 2, 3, 4, 5 and 6 sq. metres per ha. This is known as the Basal Area Factor of the instrument. Number of trees tallied multiplied by the B.A.F. will give the basal area in sq. metres per hectare.

5.3 Plot Radius Factor: This factor defines for each tree the radius of the circle within which the tree is tallied, using an instrument with a fixed critical angle.

For example, it will be clear that all the trees which are within a distance of 50 times its diameters from the observer are tallied and trees beyond this distance are not tallied. This distance is known as the " Plot Radius". This is the radius of the circle within which a tree of a given diameter is tallied for a given critical angle.

Plot Radius Factor is the reciprocal of the ratio defining the critical angle in " Diopter " provided the diameter of the tree and the plot radius are measured in some units. But we express diameter in cm and plot radius in metres. Hence plot radius factor is expressed in metre per cm of d.b.h. This is obtained by dividing the above factor by 100.

Example 1: With a 5 diopter instrument, the ratio is 5/100 and plot radius factor will be 20. Thus the plot radius factor of an instrument with critical angle of Θ is given by the reciprocal of $2 \sin \frac{\Theta}{2}$. This factor is useful in checking doubtful or border line trees.

Example 2: When we say plot radius factor 0.50 metre/cm d.b.h., it means 0.5 metre for every cm of diameter at breast height. If d.b.h. is 10cm, PRF is 5 metres and if d.b.h. is 20cm, PRF will be 10 metres.

5.4 Callibration Distance Factor: This factor indicates the distance at which a given angle will exactly cover or a prism will exactly deviate, a rectangular target which is one metre wide. C.D.F. will be 100 times the plot radius factor. If C.D.F. is 'C' for our instrument.

$$BAF = \frac{10000}{1 + 4C}$$

$$\text{Plot Radius Factor in metres per cm of diameter} = \frac{C}{100}$$

$$\text{Diopter value of instrument} = \frac{100}{C}$$

Explanation: BAF is usually marked in the instrument. If it is not marked it can be easily determined by its callibration distance factor. The C.D.F. can be determined as follows:

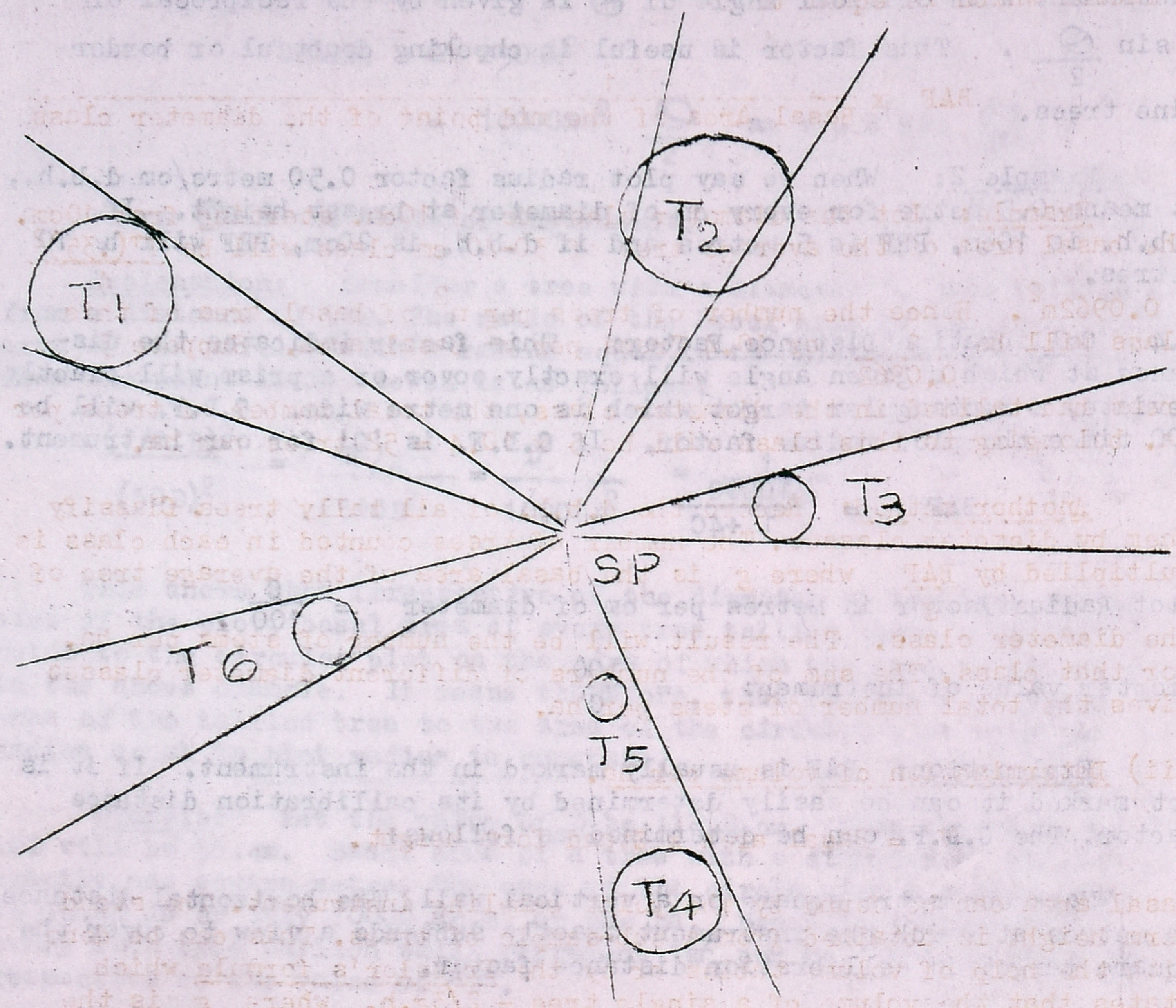
Mark one metre square on a vertical wall. The horizontal distance in metres at which the instrument exactly subtends a view to cover the square target is callibration distance factor.

6. Some Basal Area Factors and their characteristics are given below for metric system.

Basal Area Factor M^2/Ha.	Plot Radius Factor (M per cm of d.b.h.)	Prism strength in Diopters	Critical angle minutes & seconds	Callibration distance factor
0.25	1.0000	1.00	34.38	100
0.50	0.7071	1.41	56.48	70.71
1	0.5000	2.00	68.76	50.00
2	0.3536	2.83	97.24	35.36
3	0.2887	3.46	119.09	28.87
4	0.2500	4.00	137.52	25.00
5	0.2236	4.47	153.75	22.36
6	0.2041	4.90	168.43	20.41

P.T.O.

7. Effect of variation in Diameter of Trees in a stand:



In the above figure, T1, T2, T4 are tallied. But T3, T5 and T6 are not tallied. It also shows smaller trees which is nearer to the point of sampling do not tally. But bigger trees at greater distance tally. Among the trees, some are smaller and some are larger, than the average diameter. But some tally and others do not tally. These variations are of compensating nature and they will balance approximately at the average diameter trees of which all tally upto the limit of plot radius.

This works out best in an evenaged crop. But in unevenaged crops sampling has to be done separately specieswise.

8. Uses of Horizontal Point Sampling:

8.1 Determination of basal area per ha.

If 'n' trees tally the basal area per ha. will be n x BAF.

8.2 i) Number of stems per hectare: We must know the diameter of every tally tree. With this the basal area can be calculated using the formula πr^2. Then the number of stems per ha. (N) can be calculated as follows:

$$N = \frac{\text{Basal area factor of prism}}{\text{Total basal area of Tally trees}}$$

ii) Determination of number of trees of a diameter class per ha.

For this the diameters of the tally trees should be found out. The number of trees belonging to the diameter class can be obtained by

multiplying the actual number of tally trees of that diameter class by a factor which is equal to

$$BAF \times \frac{1}{\text{Basal Area of the mid point of the diameter class}}$$

Example: Let the diameter class be of 10cm. starting from 10cm. The basal area of the average tree of 30-40 cm class will be $\frac{\pi(.35)^2}{4}$ $= 0.0962m^2$. Hence the number of trees per m^2 of basal area of this class will be $\frac{1}{0.0962}$ or 10.4 Trees per m^2 basal area. Suppose 5 trees had tallied in the diameter class, the total number of trees per ha. belonging to this class will be 5 x 10.4 = 52 trees per ha.

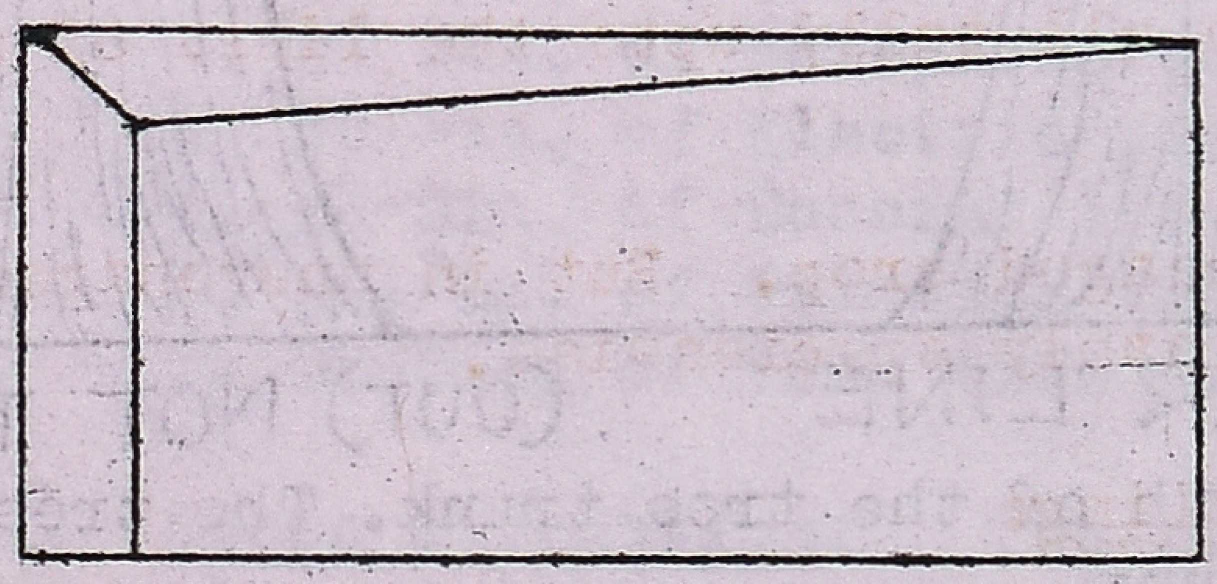
Another method: Record the d.b.h. of all tally trees. Classify them by diameter classes. The number of trees counted in each class is multiplied by $\frac{BAF}{g}$ where g is the basal area of the average tree of the diameter class. The result will be the number of stems per ha. for that class. The sum of the numbers of different diameter classes gives the total number of stems per ha.

iii) Determination of volume per ha.

V = Basal area x Stand form height.

Basal area can be found by the point sampling instrument. The stand form height is obtained from a sub-sample of trees. This can be done with the help of volume tables or by the Pressler's formula which states that the volume of a single tree = 2/3g.h. where g is the basal area of the tree and h is the height at which the diameter is half the diameter at breast height.

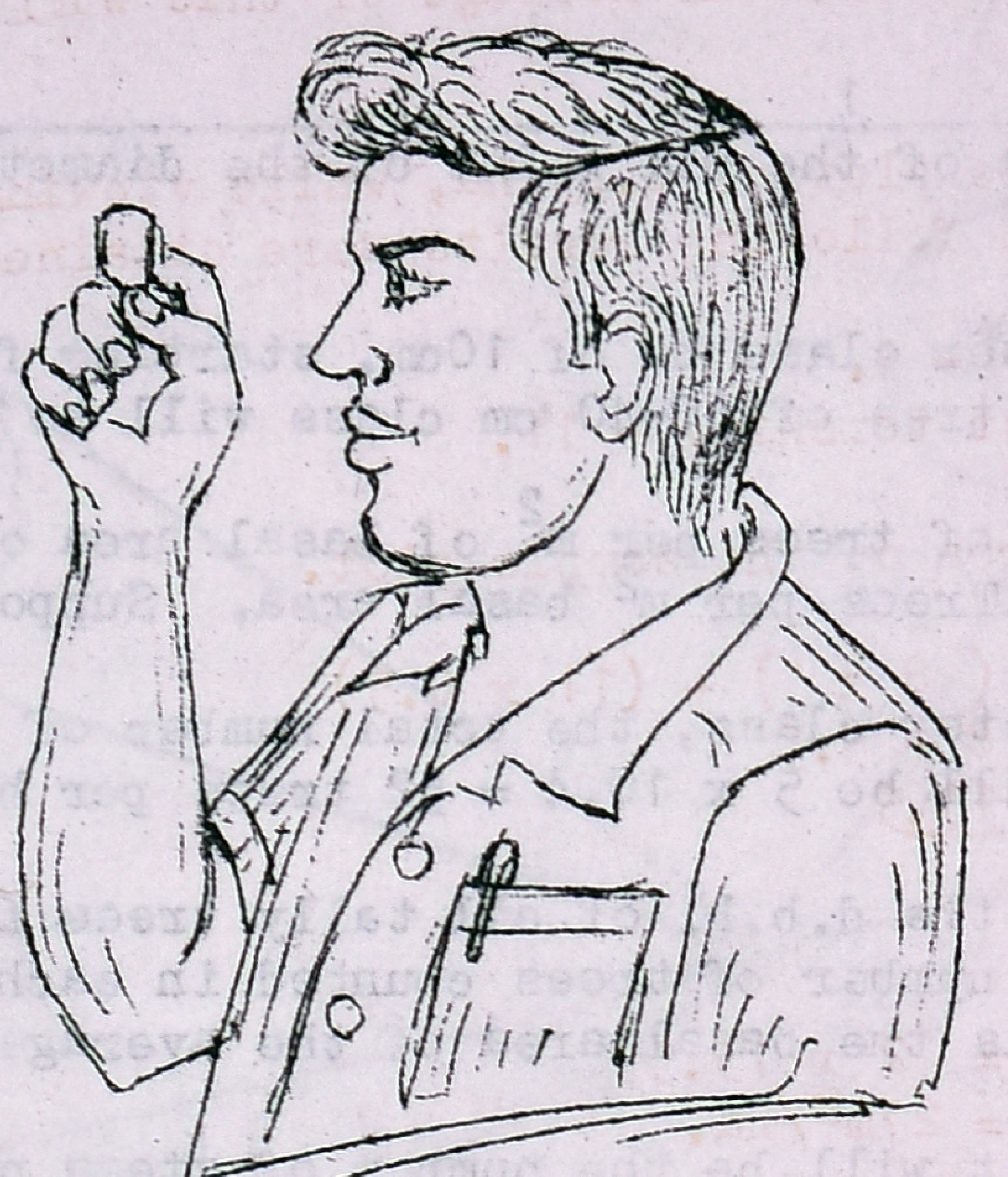
9. Wedge prism is the most commonly used instrument used in horizontal sampling as this is the simplest and the most convenient instrument. It is a wedge-shaped piece of glass of about 3cm long and 1½cm broad and 0.5 cm thick at the thicker end and about 10 gms of weight. It is provided with a hole at one end for stringing.

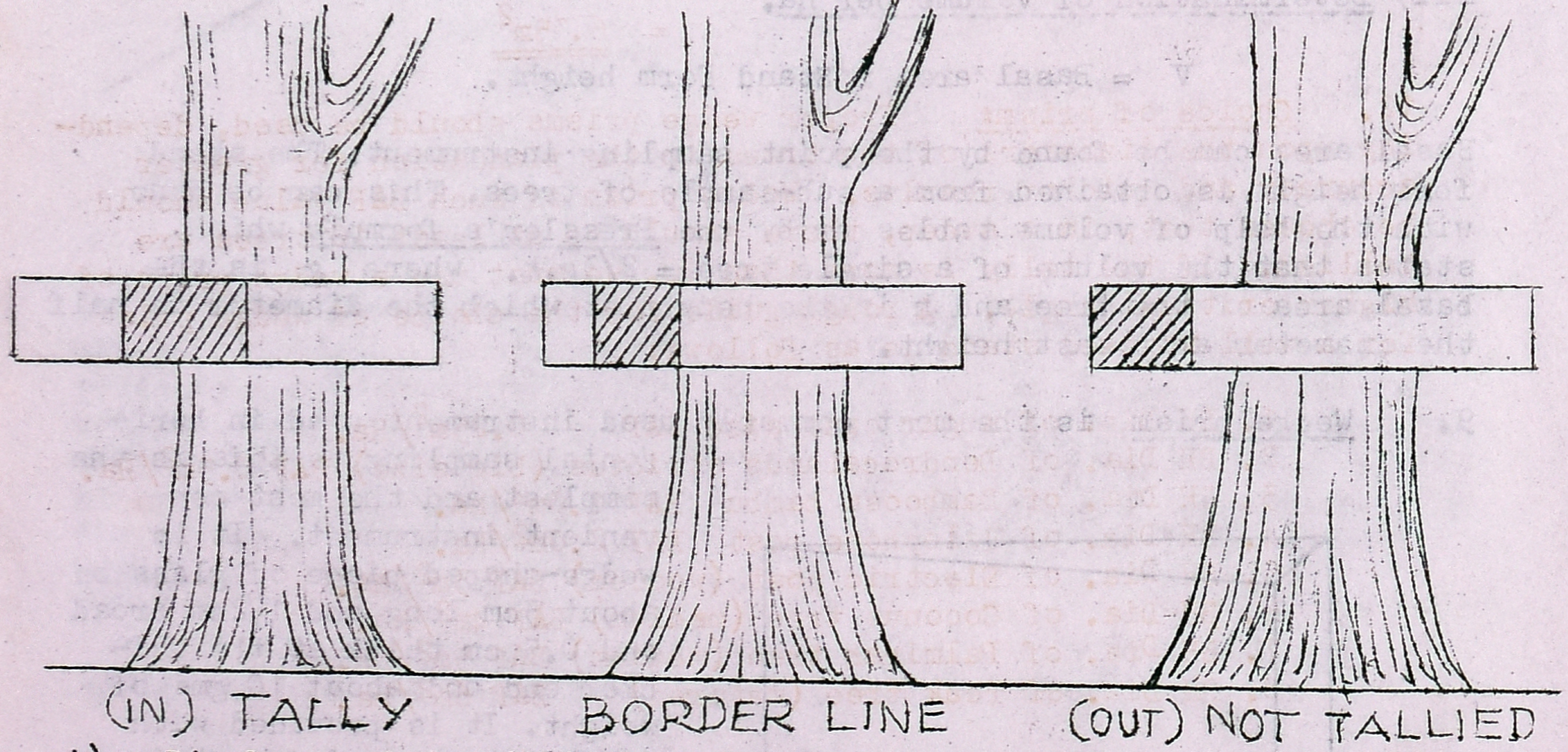


Rays of light passing through the prism are bent depending on the critical angle of the prism. This property is utilised to see if the tree tallies or not. When a tree is viewed through a wedge prism at breast height at right angles to the line of sight and simultaneously seeing the trunk of the tree directly from over the prism, it will be seen that the portion of tree viewed through the prism is displaced sideways depending on the critical angle of the prism. The tree is counted if the image overlaps the directly viewed tree. The tree is ignored if there is a gap.

10. Method of use in the field: Select a point in the forest to be sampled, from where the representative portion of the crop can be viewed. Then view the trees, holding the prism in hand between the thumb and

the middle finger, a little away from the eye in such a way that the trees are seen through the broad side. The prism should be held at right angles to the line of sight. It should be held in vertical position. The breast heights of the trees should be viewed through the prism and directly from above it. The section of the trunk will be found in one of the following three conditions.





i) Displacement is within the width of the tree trunk. The tree is considered tallied. For this one count.

ii) Its one edge may just touch the tree stem sighted directly. This is border line. For this half count.

iii) Displacement will be beyond the width of tree trunk. It is not tallied. No count.

From one point a full sweep of 360° is taken, making note of the full and half counts. This process may be repeated 2 or 3 times and counting may be done in 2nd or 3rd sweep to make sure of the accuracy that no tree is counted twice, nor any tree is left out. The number counts multiplied by the B.A.F. of the wedge prism will give the basal area in m^2/Ha.

Now select some more sampling points, say 2 or 3 and find out the basal area from those points. An average of this will give the basal area/ha.

11. Example: In a sample plot of 0.25 ha, while viewing from a wedge prism with BAF2, the following results were obtained.

i) Trees with full tally - 8.
ii) Trees with margin just touching - 11.

Find out the basal area of the sample plot.

No. of Tally trees = (8 x 1) + (11 x 0.5)
= 8 + 5.5
= 13.5

BAF is 2.

Hence Basal area = 2 x 13.5
= $27m^2$/Ha.

But the area of sample plot is 0.25 Ha.

Hence basal area of sample plot = $\frac{27m^2}{4}$

= $6.75m^2$

12. Choice of prism: Proper wedge prisms should be used, depending upon the diameters of the trees in the plantation for greater accuracy and quicker results. Wedge prism of such BAF value should be chosen that, in a sweep, there should be at least 10 trees are tallied. If the tally is more than 10, we must use a wedge prism of higher critical angle. A rough guide for the choice of wedge prism for a well stocked stand is as follows:

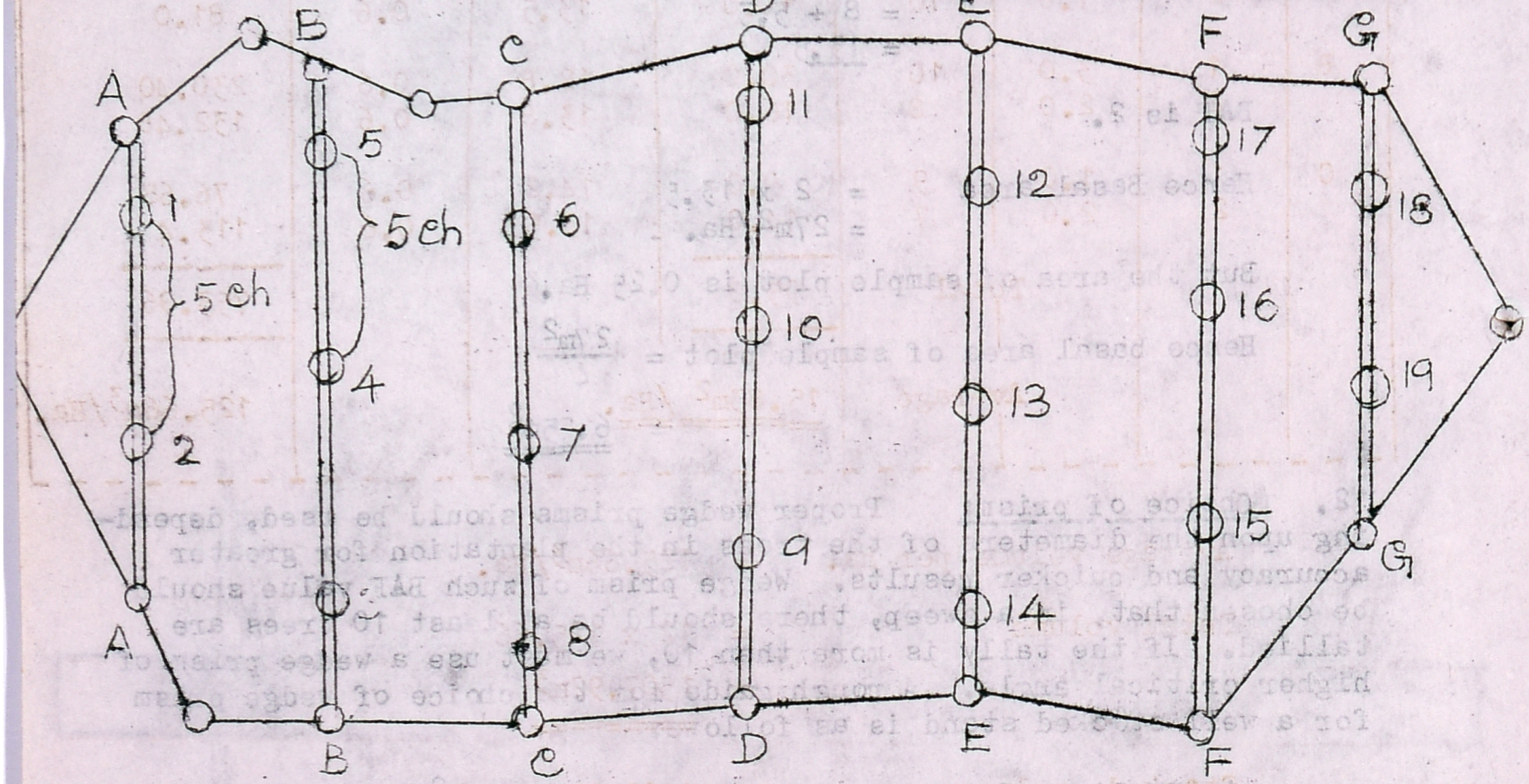
1. BH Dia. of sugar cane size BAF $0.25m^2$/Ha.
2. BH Dia. of Dendrocalamus strictus (big size) BAF $0.5m^2$/Ha.
3. BH Dia. of Bamboosa bambu BAF $1.0m^2$/ha.
4. BH Dia. of Telephone post BAF $2.0m^2$/ha.
5. BH Dia. of Electric post (wooden) BAF $3m^2$/ha.
6. BH Dia. of Coconut tree (medium) BAF $4m^2$/ha.
7. BH Dia. of Palmirah tree (medium) BAF $5m^2$/ha.
8. BH Dia. of Teak tree (matured) BAF $6m^2$/ha.

13. Slope correction: The prism has to be held precisely over the sample point. The distance of the eye from the point does not affect the amount of image shift. It is quite essential that the prism is held in vertical position in level terrain and at right angles to the line of sight on sloping ground. Otherwise larger bias in the tree tally may result. In hilly areas of more than 10° gradient, correction for slope is necessary. Slope less than 10° may be ignored since the error is less than 3%.

If the prism is not at right angle to the line of sight, too few trees are counted while a tilt in vertical plane increases the number of tally trees. Hence in a sloping ground, the angle of slope can be found out by an Abney's level or any other slope measuring instrument as it will be difficult in hilly country to hold the prism such that it is at right angle to the line of sight. The tally number obtained may be multiplied by the secant of the slope angle. A slope angle of 25% causes an error of about 10%.

14. <u>Selection and number of sample points:</u> Sample points should be selected so as to represent all types of growth and stocking in correct proportion. Following method may be adopted.

Take the surveyed sketch of the plantation. Draw systematic grid lines 20 to 100 metres apart from a convenient base line. Select points at random or systematically on the grid lines 20 to 100 metre apart depending upon the pattern selected.



Take the above sketch to the field. The gird lines may be given alphabetical number and points selected may be given numericals. The alphabetical number may be marked on both the sides of the plantation. Then the sample points may be selected and located with a peg. Even if there is a blank, do not change the point.

A few trees may be given a red band at b.h. to facilitate easy sighting of the b.h. mark of the trees. Tallied trees may be given a red dot for identification. The height of the tallest tree may be measured and it may be identified with a cross mark. The result of the sampling may be tabulated in a sheet of paper or in the note book.

Name of R.F.: Poomparai
Name of Division: Vellore

Name of plantation :: Paravamalai Range, Polur
Year of Plantation :: 1970
Species :: Eucalyptus hybrid.
Area : 12.0 Ha. Espacement: 4m x 2m

Grid No.	Sample Point No.	BAF of wedge prism	No. of trees tallied	Basal area m^2/Ha.	Height of tallest tree	Form Factor	Volume m^3/Ha.
A	1	2.0	8	16.0	12.5	0.6	120.0
	2	1.0	10	10.0	13.5	0.6	81.0
B	1	3.0	10	30.0	12.8	0.6	230.40
	2	2.0	8	16.0	13.8	0.6	132.48
C	1	1.0	9	9.0	14.2	0.6	76.68
	2	2.0	7	14.0	13.5	0.6	113.4
		Total		95.0			753.96
		Average		15.83m^2/Ha.			125.66m^3/Ha.

Average volume per ha. = 125.66m^3/Ha.

Total volume = 12 x 125.66

= 1507.92m^3

Stacked volume = 1507.92 x 1.6

= 2412.67m^3

Yield by weight:

Pulp wood - Green weight 1507.92 x 1.2 = 1809.5 Ton.
Pulp wood Air dry weight 1507.92 x 0.8 = 1206.34 Ton.
Yield of bark = $1507.92 \times \frac{22}{100}$

= 331.74 Tonne.

15. Advantages of wedge prism:

i) It is quite cheap.
ii) It is quite easy to use and does not require high degree of skill. It is quite quick also.
iii) Method can be easily learnt by the field staff.
iv) It is not a strain to the eye. It can be used in dim light conditions also.
v) Its weight is much less. It can be carried in pockets.

APPENDIX 4

USE OF LOGARITHMS

1. INTRODUCTION Logarithm is a labour saving device with the aid of which arithmatical operations like multiplication, division, etc. can be carried out easily.

1.1 Definition: Logarithm (Log) of a number to a given base is the index (or the power) to which the base is to be raised to equal the given number.

Thus if $a^x = N$, then

x is called the logarithm of N with respect to the base a and this can be written as $\text{Log}_a N = x$.

In practice, log is expressed with reference to a constant base i.e. number 10, and logarithemic tables are drawn up on the bases. The base is always 10. If we express log of 100 is 2, it means log of 100 to the base of 10 is 2. ($10^2 = 100$).

2. Use of Logarithms:

i) The logarithm of a product is equal to the sum of log of its factors

Log of M x N = Log of M + Log of N.

ii) The log of a quotient is equal to the log of the divident minus the log of the devisor. Thus

$$\text{Log of } \frac{M}{N} = \text{Log } M - \text{Log of } N.$$

iii) The log of a number raised to any power integral or fractional is equal to the product of the log of the number and the index of the power.

If $M = A^x$, Log of M to the base A = x

$$M^r = (A^x)^r = A^{xr}.$$

Therefore Log of Mr = Xr.

= Log of M multiplied by the index of the power i.e. r.

3.1 Use of Log Tables: In this tables, logarithm of various numbers to the base 10 only will be furnished.

Every logarithm will have 2 parts i.e., the characteristic or index which is the integral part, and mantissa or the decimal or fractional part.

3.2 Characteristic: The characteristic of the logarithm of a number greater than one is positive and is one less than the number of digits in the whole part of the number.

The characteristic of the logarithm of a number less than one is negative and is one more than the number of zeros which immediately follow the decimal part.

Example:

Logarithm of numbers	Characteristic	Mantissa
5 6.7 8	3	+ a fraction
567.8	2	+ "
56.78	1	+ "
5.678	0	+ "
0.5678	-1 written as $\bar{1}$	+ "
0.05678	-2 " $\bar{2}$	+ "
0.005678	-3 " $\bar{3}$	+ "
.0005678	-4 " $\bar{4}$	+ "

3.3 Mantissa: The mantissa of the logarithm of a number is found from the log-tables.

To find the logarithm of 2478, we know that the characteristic will be 4-1 = 3. In the table, run down the first column to the number 24 and then on this row, go to the column, with number 7 at the top. In this place we have entry 3927. In the same row read the number in column 8 under the mean difference section. The entry is 14. Add this 14 to 3927; We get 3941.

Hence Log of 2478 = 3.3941
Log of 247.8 = 2.3941
Log of 24.78 = 1.3941
Log of 2.478 = 0.3941
Log of 0.2478 = $\bar{1}$.3941
Log of 0.02478 = $\bar{2}$.3941
Log of 0.002478 = $\bar{3}$.3941
Log of 0.0002478 = $\bar{4}$.3941

Hence the mantissima of all numbers consisting of the same significant digits arranged in the same order, but differing only in the position of their decimal points are the same.

4. ANTI LOGARITHMS: The number corresponding to a given logarithm is called its anti-logarithm.

Example: Log 2.478 = 0.3941
Anti log 0.3941 = 2.478

Anti-log can be found out from the Anti-arithmatic Tables. Let us find out the anti-log of 1.3941. Here 1 is the characteristic and 0.3941 is the mantissa. Corresponding to the mantissa the table of the anti-logarithms gives the figure 2478. The characteristic is one here. Hence the original number for which log is availabe had 2 figures in the integral part.

Hence Anti-log 1.3941 = 24.78

Similarly Anti-log 2.3941 = 247.8

" 3.3941 = 2478

" 4.3941 = 24780

" 0.3941 = 2.478

" $\bar{1}.3941$ = 0.2478

" $\bar{2}.3941$ = 0.02478

Example:

1. Find the product of 27.58 x 98.06.

Product = Log of 27.58 + Log 98.06
= 1.4406 + 1.9915
= 3.4321

Anti-log of 3.4321 = 2705
Hence the product = 2705.

The product by actual multiplication will be 2704.4948

2. Find the Quotient of .586 ÷ 6.32

Quotient = Log .586 - Log 6.32

= $\bar{1}.7679$ - .8007

= $\bar{2}.9672$

Anti-log of $\bar{2}.9672$ = <u>.09272</u>

3. Find the value of 3.52^3

Let the value to be found be V.

V = 3 x Log of 3.52

i.e. 3 x .5465

i.e. <u>1.6395</u>

Anti-log 1.6395 = <u>43.60</u>

Hence $(3.52)^3$ = <u>43.60</u>

4. Find the cube root of 130.

Cube root of 130 = $\frac{1}{3}$ Log of 130.

i.e. $\frac{1}{3}$ of 2.1139

= .7046

Anti-log of .7046 = 5.065

Hence cube root of 130 = <u>5.065</u>

APPENDIX 5

NATURAL SINES, COSINES AND TANGENTS OF ANGLES

Degrees	Sines	Cosones	Tangents	Degrees	Sines	Cosones	Tangents
0	.00000	1.00000	.00000	37	.60181	.79864	.75355
1	.01745	.99985	.01746	38	.61566	.78801	.78129
2	.03490	.99939	.03492	39	.62932	.77715	.80978
3	.05234	.99863	.05241	40	.64279	.76604	.83910
4	.06976	.99756	.06993	41	.65606	.75471	.86929
5	.08716	.99619	.08749	42	.66913	.74314	.90040
6	.10453	.99452	.10510	43	.68200	.73135	.93252
7	.12187	.99255	.12278	44	.69466	.71934	.96569
8	.13917	.99027	.14054	45	.70711	.70711	1.00000
9	.15643	.98769	.15838	46	.71934	.69466	1.03553
10	.17365	.98481	.17633	47	.73135	.68200	1.07237
11	.19081	.98163	.19438	48	.74314	.66913	1.11061
12	.20791	.97815	.21256	49	.75471	.65606	1.15037
13	.22495	.97437	.23087	50	.76604	.64279	1.19175
14	.24192	.97030	.24933	51	.77715	.62932	1.23490
15	.25882	.96593	.26795	52	.78801	.61566	1.27994
16	.27564	.96126	.28675	53	.79864	.60181	1.32704
17	.29237	.95630	.30573	54	.80902	.58778	1.37638
18	.30902	.95106	.32492	55	.81915	.57358	1.42815
19	.32557	.94552	.34433	56	.82904	.55919	1.48256
20	.34202	.93969	.36397	57	.83867	.54464	1.53987
21	.35837	.93358	.38386	58	.84805	.52992	1.60033
22	.37461	.92718	.40403	59	.85717	.51504	1.66428
23	.39073	.92050	.42447	60	.86603	.50000	1.73205
24	.40674	.91355	.44523	61	.87462	.48481	1.80405
25	.42262	.90631	.46631	62	.88295	.46947	1.88073
26	.43837	.89879	.48773	63	.89101	.45399	1.96261
27	.45399	.89101	.50953	64	.89879	.43837	2.05030
28	.46947	.88295	.53171	65	.90631	.42262	2.14451
29	.48481	.87462	.55431	66	.91355	.40674	2.24604
30	.50000	.86603	.57735	67	.92050	.39073	2.35585
31	.51504	.85717	.60086	68	.92718	.37461	2.47509
32	.52992	.84805	.62487	69	.93358	.35837	2.60509
33	.54464	.83867	.64941	70	.93969	.34202	2.74748
34	.55919	.82904	.67451	71	.94552	.32557	2.90421
35	.57358	.81915	.70021	72	.95106	.30902	3.07768
36	.58778	.80902	.72654	73	.95630	.29237	3.27085

Degrees	Sines	Cosines	Tangents	Degrees	Sines	Cosines	Tangents
74	.96126	.27564	3.48741	82	.99027	.13917	7.11537
75	.96593	.25882	3.73205	83	.99255	.12187	8.14435
76	.97030	.24192	4.01078	84	.99452	.10453	9.51436
77	.97437	.22495	4.33148	85	.99619	.08716	11.430
78	.97815	.20791	4.70463	86	.99756	.06976	14.301
79	.98163	.19081	5.14455	87	.99863	.05234	19.081
80	.98481	.17365	5.67128	88	.99939	.03490	28.636
81	.98769	.15643	6.31375	89	.99985	.01745	57.290
				90	1.00000	.00000	∞

Note: To find slope per cent for a given angle, multiply the tangent value of that angle by 100.

APPENDIX 6

AREA OF CIRCLES OF DIAMETERS 1 CENTIMETER TO 120 CENTIMETRES

Diameter in centimetres	Area of circle in square metres	Diameter in centimetres	Area of circle in square metres.
1	0.00008	37	0.10752
2	0.00031	38	0.11341
3	0.00071	39	0.11946
4	0.00126	40	0.12566
5	0.00196	41	0.13203
6	0.00283	42	0.13854
7	0.00385	43	0.14522
8	0.00503	44	0.15205
9	0.00636	45	0.15904
10	0.00785	46	0.16619
11	0.00950	47	0.17349
12	0.01131	48	0.18096
13	0.01327	49	0.18857
14	0.01539	50	0.19635
15	0.01767	51	0.20428
16	0.02011	52	0.21237
17	0.02270	53	0.22062
18	0.02545	54	0.22902
19	0.02835	55	0.23758
20	0.03142	56	0.24630
21	0.03464	57	0.25518
22	0.03801	58	0.26421
23	0.04155	59	0.27340
24	0.04524	60	0.28274
25	0.04909	61	0.29225
26	0.05309	62	0.30191
27	0.05726	63	0.31172
28	0.06158	64	0.32170
29	0.06605	65	0.33188
30	0.07069	66	0.34212
31	0.07548	67	0.35257
32	0.08042	68	0.36317
33	0.08553	69	0.37393
34	0.09079	70	0.38485
35	0.09621	71	0.39592
36	0.10179	72	0.40715

Diameter in centimetres	Area of circle in square metres	Diameter in centimetres	Area of circle in square metres
73	0.41854	97	0.73898
74	0.43008	98	0.75430
75	0.44179	99	0.76977
76	0.45365	100	0.78540
77	0.46566	101	0.80118
78	0.47784	102	0.81713
79	0.49017	103	0.83323
80	0.50265	104	0.84949
81	0.51530	105	0.86590
82	0.52810	106	0.88247
83	0.54106	107	0.89920
84	0.55418	108	0.91609
85	0.56745	109	0.93313
86	0.58088	110	0.95033
87	0.59447	111	0.96769
88	0.60821	112	0.98520
89	0.62211	113	1.00287
90	0.63617	114	1.02070
91	0.65039	115	1.03869
92	0.66476	116	1.05683
93	0.67920	117	1.07513
94	0.69398	118	1.09359
95	0.70882	119	1.11220
96	0.72382	120	1.13097

APPENDIX 7

VOLUME TABLE FOR TEAK

TECTONA GRANDIS

Volume of timber in the round including bark(local C.P. definition) - quarter girth measurement - by girth classes and height classes to the nearest 1/2 cubic foot

Girth class	Height class (feet)				
	11'--30'	31'--50'	51'--70	71'--90'	91'--100'
Over 7"-10"	..	..	..	..	..
" 10"-13"	1/2	1	11/2	..	..
" 13"-16"	1	11/2	11/2	..	..
" 16"-19"	1	2	31/2	..	..
" 19"-22"	1	21/2	4	..	..
" 22"-25"	11/2	3	5	7	..
" 25"-31"	11/2	4	7	10	..
" 31"-37"	2	51/2	10	141/2	..
" 37"-43"	3	8	14	20	..
" 43"-49"	4	101/2	181/2	26	36
" 49"-55"	51/2	141/2	24	331/2	44
" 55"-61"	71/2	19	301/2	41	521/2
" 61"-67"	10	231/2	37	491/2	62
" 67"-73"	13	281/2	44	58	72
" 73"-79"	..	34	511/2	671/2	83
" 79"-85"	..	40	591/2	77	941/2
" 85"-91"	..	..	67	86	1051/2
" 91"-97"	..	..	751/2	961/2	1181/2
" 97"-103"	..	..	83	1051/2	1291/2

APPENDIX 8

TOP HEIGHT BY SITE QUALITY AND AGE

TECTONA GRANDIS

Site Quality	I			II			III			IV		
	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0	2.0	1.0	0
Age in years												
5	42	37	33	33	28	24	24	20	16	16	13	10
10	62	56	50	50	44	38	38	32	27	27	21	15
15	76	69	62	62	55	48	48	41	34	34	27	19
20	87	79	71	71	63	55	55	47	39	39	31	23
25	95	86	78	78	69	61	61	52	44	44	35	27
30	101	92	83	83	74	65	65	56	47	47	38	30
35	106	97	88	88	78	69	69	60	51	51	42	32
40	111	102	92	92	83	73	73	64	54	54	45	35
45	116	106	96	96	86	77	77	67	57	57	47	38
50	120	110	100	100	90	80	80	70	60	60	50	40
55	124	113	103	103	93	83	83	73	62	62	52	42
60	127	117	106	106	96	85	85	75	65	65	54	44
65	130	120	109	109	99	88	88	78	67	67	56	46
70	134	123	112	112	101	91	91	80	69	69	58	47
75	137	126	115	115	104	93	93	82	71	71	60	49
80	140	129	118	118	106	95	95	84	73	73	61	50
85	143	132	120	120	109	97	97	86	74	74	63	51
90	146	135	123	123	111	99	99	87	76	76	64	52
95	149	137	125	125	113	101	101	90	77	77	65	53
100	152	140	127	127	115	103	103	91	78	78	66	54

Note: Top height is given in feet.

APPENDIX 9

CONVERSION OF INCHES TO CENTIMETRES

1 inch = 2.5399978 cm.

Inches	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Centimetres									
0	0	0.25	0.51	0.76	1.02	1.27	1.52	1.78	2.03	2.29
1	2.54	2.79	3.05	3.30	3.56	3.81	4.06	4.32	4.57	4.83
2	5.08	5.33	5.59	5.84	6.10	6.35	6.60	6.86	7.11	7.37
3	7.62	7.87	8.13	8.38	8.64	8.89	9.14	9.40	9.65	9.91
4	10.16	10.41	10.67	10.92	11.18	11.43	11.68	11.94	12.19	12.45
5	12.70	12.95	13.21	13.46	13.72	13.97	14.22	14.48	14.73	14.99
6	15.24	15.49	15.75	16.00	16.26	16.51	16.76	17.02	17.27	17.53
7	15.78	18.03	18.29	18.54	18.80	19.05	19.30	19.56	19.81	20.07
8	20.32	20.57	20.83	21.08	21.34	21.59	21.84	22.10	22.35	22.61
9	22.86	23.11	23.37	23.62	23.88	24.13	24.38	24.64	24.89	25.15

APPENDIX - 10

CONVERSION OF FEET TO METRES

1 foot = 0.3048 m.

Feet	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
					Metres					
0	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27
1	0.30	0.34	0.37	0.40	0.43	0.46	0.49	0.52	0.55	0.58
2	0.61	0.64	0.67	0.70	0.73	0.76	0.79	0.82	0.85	0.88
3	0.91	0.94	0.98	1.01	1.04	1.07	1.10	1.13	1.16	1.19
4	1.22	1.25	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.49
5	1.52	1.55	1.59	1.62	1.65	1.68	1.71	1.74	1.77	1.80
6	1.83	1.86	1.89	1.92	1.95	1.98	2.01	2.04	2.07	2.10
7	2.13	2.16	2.19	2.23	2.26	2.29	2.32	2.35	2.38	2.41
8	2.44	2.47	2.50	2.53	2.56	2.59	2.62	2.65	2.68	2.71
9	2.74	2.77	2.80	2.83	2.87	2.90	2.93	2.96	2.99	3.02

APPENDIX 11

CONVERSION OF SQUARE FEET TO SQUARE METRES

Conversion factor 1Sq.feet = 0.092903 Sq.metre

Sq. feet	0 m^2	1 m^2	2 m^2	3 m^2	4 m^2	5 m^2	6 m^2	7 m^2	8 m^2	9 m^2
0	0	0.09	0.19	0.28	0.37	0.46	0.56	0.65	0.74	0.84
10	0.93	1.02	1.11	1.21	1.30	1.39	1.49	1.58	1.67	1.77
20	1.86	1.95	2.04	2.14	2.23	2.32	2.42	2.51	2.60	2.70
30	2.79	2.88	2.97	3.07	3.16	3.25	3.34	3.44	3.53	3.62
40	3.72	3.81	3.90	3.99	4.09	4.18	4.27	4.37	4.46	4.55
50	4.65	4.74	4.83	4.92	5.02	5.11	5.20	5.29	5.39	5.48
60	5.57	5.67	5.76	5.85	5.95	6.04	6.13	6.22	6.32	6.41
70	6.50	6.60	6.69	6.78	6.87	6.97	7.06	7.15	7.25	7.34
80	7.43	7.53	7.62	7.71	7.80	7.90	7.99	8.08	8.18	8.27
90	8.36	8.45	8.55	8.64	8.73	8.83	8.92	9.01	9.10	9.20

APPENDIX 12

CONVERSION OF CUBIC FEET TO CUBIC METRES

Cubic feet	0	1	2	3	4	5	6	7	8	9
	Cubic metres									
0	0	0.0283	0.0566	0.850	0.1133	0.1416	0.1699	0.1982	0.2265	0.2549
10	0.2832	0.3115	0.3398	0.3681	0.3964	0.4248	0.4531	0.4814	0.5097	0.5380
20	0.5663	0.5947	0.6230	0.6513	0.6796	0.7079	0.7362	0.7646	0.7929	0.8212
30	0.8495	0.8778	0.9061	0.9345	0.9628	0.9911	1.0194	1.0477	1.0760	1.1044
40	1.1327	1.1610	1.1893	1.2176	1.2459	1.2743	1.3026	1.3309	1.3592	1.3875
50	1.4159	1.4442	1.4725	1.5008	1.5291	1.5574	1.5858	1.6141	1.6424	1.6707
60	1.6990	1.7273	1.7557	1.7840	1.8123	1.8406	1.8689	1.8972	1.9256	1.9539
70	1.9822	2.0105	2.0388	2.0671	2.0955	2.1238	2.1521	2.1804	2.2087	2.2370
80	2.2654	2.2937	2.3220	2.3503	2.3786	2.4069	2.4353	2.4636	2.4919	2.5202
90	2.5485	2.5768	2.6052	2.6335	2.6618	2.6901	2.7184	2.7467	2.7751	2.8034

APPENDIX 13

CONVERSION OF SQUARE MILES TO SQUARE KILOMETRES

Conversion factor: 1 Sq.mile = 2.58999 Sq.km.

Sq. miles	0	1	2	3	4	5	6	7	8	9
	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km	Sq.km
0	0	2.59	5.18	7.77	10.36	12.95	15.54	18.13	20.72	23.31
10	25.90	28.45	31.08	33.67	36.26	38.85	41.44	44.03	46.62	49.21
20	51.80	54.39	56.98	59.57	62.16	64.75	67.34	69.93	72.52	75.11
30	77.70	80.29	82.88	85.47	88.06	90.65	93.24	95.83	98.42	101.02
40	103.60	106.20	108.78	111.37	113.96	116.55	119.14	121.73	124.32	126.91
50	129.50	132.09	134.68	137.27	139.86	142.45	145.04	147.63	150.22	152.81
60	155.40	157.99	160.58	163.17	165.76	168.35	170.94	173.53	176.12	178.71
70	181.30	183.89	186.48	189.07	191.66	194.25	196.89	199.93	202.02	204.61
80	207.20	209.79	212.38	214.97	217.56	220.15	222.74	225.33	227.92	230.51
90	233.10	235.69	238.28	240.87	243.46	246.05	248.64	251.23	253.82	256.41

APPENDIX 14

ACRES TO HECTARES

Based on 1 inch = 25.4 millimetres

Acres	0	1	2	3	4	5	6	7	8	9
	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
0	0	0.40	0.81	1.21	1.62	2.02	2.43	2.83	3.24	3.64
10	4.05	4.45	4.86	5.26	5.66	6.07	6.47	6.88	7.28	7.69
20	8.09	8.50	8.90	9.31	9.71	10.12	10.52	10.93	11.33	11.74
30	12.14	12.55	12.95	13.35	13.76	14.16	14.57	14.97	15.38	15.78
40	16.19	16.60	17.00	17.40	17.81	18.21	18.61	19.02	19.42	19.83
50	20.23	20.64	21.04	21.45	21.85	22.26	22.66	23.07	23.47	23.88
60	24.28	24.69	24.09	25.50	25.90	26.30	26.70	27.11	27.52	27.92
70	28.33	28.73	29.14	29.54	29.95	30.35	30.76	31.16	31.57	31.97
80	32.37	32.78	33.18	33.59	32.99	34.39	34.80	35.21	35.61	36.02
90	36.42	36.83	37.23	37.64	33.04	38.45	38.85	39.25	39.66	40.06

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